IRISH FISHERIES INVESTIGATIONS

SERIES A (Freshwater)

No. 23 (1983)

Advances in Fish Biology in Ireland

A SEMINAR OF THE NATIONAL COMMITTEE FOR BIOLOGY
OF THE
ROYAL IRISH ACADEMY

23 AND 24 APRIL, 1981.

Edited by
CHRISTOPHER MORIARTY

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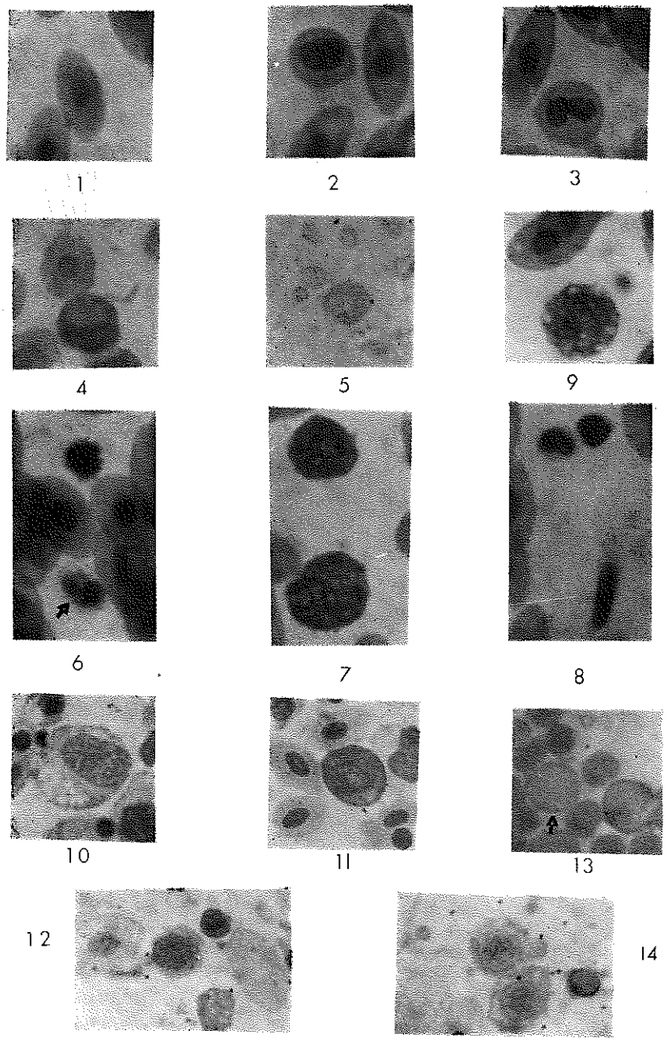

1. Circulating erythrocyte. 2. Circulating early granulocyte. 3. Circulating 2-lobed mature granulocyte. 4. Circulating granulocyte (Sudan Black). 5. Circulating granulocyte (PAS). 6. Circulating small lymphocyte; polychromatocyte also present (arrow). 7. Circulating large lymphocyte. 8. Two round and one spindle thrombocyte. 9. Circulating monocyte. 10. Large lymphoid haemoblast in kidney imprint. 11. Small lymphoid haemoblast in kidney imprint. 12. Lymphoblast/erythroblast in kidney imprint. 13. Prolymphocyte in kidney imprint. 14. Proerythrocytes in spleen imprint. All cells stained with Wright Giemsa unless otherwise stated. Magnification x 1,000.

Frontispiece

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Contents

Introduction

by

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The dominant figure in Irish fisheries research for nearly forty years until his retirement in 1975 was Arthur Went. Indeed, for a period of twenty years or so publications by other workers in the field were rarities while those of Went appeared with an admirable regularity.

A dramatic change in this situation began in the 1950's. The Inland Fisheries Trust was incorporated in 1951 with Michael Kennedy as its Secretary. Kennedy's amateur studies developed to a degree which few professionals could emulate and in the 1960's the Trust recruited a number of biologists. In the meanwhile a major increase in technical staff numbers in the Fisheries Division of the Department of Lands was in progress, having begun in 1959. In 1960 the fisheries research vessel *Cú Feasa* was commissioned. The Salmon Research Trust was incorporated in 1955. Liaison between the Fisheries Division and the Universities began in 1959 with the establishment of the first of many research studentships and several University Departments became actively engaged in research on fish and in the field of aquatic biology in general. The Northern Ireland Government established a fisheries laboratory in Coleraine in 1964, transferring its staff from Belfast. The staff of the Inland Fisheries Trust was absorbed in the Central Fisheries Board established in 1980.

In effect, research in fisheries has been in progress on this wide front for twenty-five years, a total of four Government or State-aided institutes and six university colleges being involved. An informal group of research workers in freshwater biology meets annually; a similar group of marine workers was set up but has not met in recent years. The situation has been that, apart from the circulation of published material, there has been no formal exchange of information between the various research organisations.

The National Committee for Biology of the Royal Irish Academy therefore decided to hold a seminar which would provide a basis for such a meeting. Publication of the papers presented would result in a document giving an indication of the development of fishery research in Ireland over this period of rapid expansion of the discipline. The chairman of the National Committee for Biology at the time this decision was taken was Arthur Went. His tragic death a few months later robbed this and many other committees of an enthusiastic and valued worker. It was decided to dedicate the Proceedings of the seminar to his memory.

The Seminar took place in the Academy House in Dublin on 23 and 24 April, 1981. An address of welcome was given by the President of the Royal Irish Academy, Professor P. MacCana. This was followed by an introductory speech by the Minister for Fisheries and Forestry, Mr. P. Power, T.D. The registered attendance comprised 42 full participants and 28 student participants. Eighteen papers were presented in three sessions.

The papers presented covered most of the areas in which research is in progress in fin fish biology in Ireland. The most notable omission was the subject of population studies of demersal species including cod *Gadus morhua* L., whiting *Merlangius merlangus* (L.) and plaice *Pleuronectes platessa* L. Extensive research on these and other species is in progress both in Dublin and in Coleraine. Two further omissions were the sea trout *Salmo trutta* L. and the eel *Anguilla anguilla* (L.), both subjects of long-term studies based in Dublin.

All the papers except that on the Gobiesocidae are concerned with studies on fish of commercial importance whether in the field of sport fishing as with the cyprinids and trout or in commercial fishing or aquaculture. The themes of stock assessment and stock identification are the principal ones and reflect growing concern for the survival of exploited populations. The work reported on disease and aquaculture deals in part with the direct study of diseases of economic importance and in part with work in histology and physiology.

This seminar has been a milestone in the history of fisheries research in Ireland. It marks the conclusion of twenty-five years of expansion in the extent of the research effort, combined with a marked change of emphasis from the largely descriptive work of the previous seventy-five years to a much more analytical approach.

As a result of the descriptive work of the more distant past, a reasonably comprehensive account of the distribution of the major fish stocks can be given. Knowledge of this distribution is the basis of the country's fishing industry which appears to be exploiting all acceptable market species at a

high level of intensity. The scope for increased fishing effort is almost certainly limited and the necessity is for the enactment and enforcement of effective conservation measures. It is difficult to persuade fishermen of the need to comply with conservation measures in the absence of convincing evidence that the measures are necessary to maintain or improve the fish stocks.

The sources of papers presented to the Seminar show that the number of institutions now engaged in fishery research is greater than the number of individual biologists working in the subject in the early 1950's. To that extent evidence has been provided of the growth in research effort. The papers themselves testify to the high academic quality of that research. The question which remains is that of the value of the work in terms of contributing to the well-being of the fishing industry.

Two considerable achievements stand out in the field of direct contributions. The first is the high degree of proficiency in assessing pelagic fish stocks. This, in the case of the Celtic Sea herring led to the identification of undesirable trends in exploitation of the stock together with a warning of its imminent collapse. Unfortunately conservation measures were not enacted in time to avert this. The second relates to aquaculture in which feeding experiments demonstrated the feasibility of developing a trout-farming industry based on the use of pellet feed. One might mention as a third feature, the rapid improvement in efficiency in diagnosis of diseases of farmed fish which has resulted in part from more basic research work on the species.

The picture that emerges is one of an array of exceedingly complex situations. The work in progress has served to demonstrate in particular that it is possible at this stage only to point the way to developing effective fishery management policy. No fewer than three of the papers describe the development of techniques for stock assessment. The application of the techniques will take many more years. Seven papers are largely descriptive but include such discoveries as the existence of numerous genetically isolated breeding populations of salmonids and more or less unsuspected migratory patterns of freshwater fish. The lack of such information in the past has led in cases to extremely wasteful attempts at stock enhancement which can be avoided in the future.

Irish fish stocks are exposed to severe pressures from various sources including pollution and water abstractions, increased fishing effort by native fishermen and by foreign boats, both legitimate and otherwise. The deliberations of this Seminar have shown that, within the country, advances in the study of fish biology have been made which should enable fishery scientists to formulate practical solutions to the problems. Future developments will see sustained improvements in data gathering and analysis leading to better management of the fishery resources.

Carp (*Cyprinus carpio* L.) in Ireland

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INTRODUCTION

The Inland Fisheries Trust Incorporated was charged with the promotion and development of coarse fish angling in Ireland until the dissolution of the Trust in October 1980. In order to obtain essential data on Irish coarse fishes a programme of research was begun in 1964. The objectives of the research programme were (a) to establish in adequate detail the life histories of the different coarse fishes and (b) to obtain data on the ecological conditions in the various waters in which these fishes occurred. The results of research on the biology of some of these fishes have already been published (Bracken and Kennedy 1967; Kennedy 1969a, Kennedy 1969b; Kennedy and Fitzmaurice 1968, 1969, 1970, 1972 and 1974).

DISTRIBUTION OF CARP IN IRELAND

Huet (1960) states that carp *Cyprinus carpio* L. originated from eastern Europe in the basins of the Black Sea, Azov Sea and the Caspian Sea. They are found in Asia across to China and also in Japan. The introduction of carp farming to western Europe goes back to the middle ages. According to Tate Regan (1911) the first mention of carp in England is by Dame Juliana Berner in the famous "Boke of St. Albans" in 1496.

Introductions of the species into Ireland although sporadic and largely abortive, date back as far as the seventeenth century. Went (1950) refers to proposed introductions by Richard Boyle the Great Earl of Cork in 1634 and 1640 and he also gives other historical references to carp. Charles Smith in his History of Cork mentions carp in the Awbeg River. Rutty (1772) noted that carp was said to have been brought to Ireland for the first time during the reign of James I, 1603-1625. Tighe (1802) mentions carp in the River Barrow. Daniel (1807) and Windele (1849) both stated that carp were to be found in the lakes of Killarney. Carp were also introduced into Lough Inchiquin about 1790. Thompson (1856) noted that carp were in the following localities; Montalto and Killyeagh, Co. Down; Markethill, Co. Armagh; Abbeyville, Co. Dublin and Counties Galway and Sligo.

In the waters mentioned above carp are not found to-day. Development and survey work carried out on the Lakes of Killarney, Lough Inchiquin and at Abbeyville have never shown any signs of carp. Indeed in 1815 a writer, describing the release of tench into Lough Inchiquin, noted the absence of carp (Went 1950).

The present distribution of carp in Ireland can be considered in two parts—pre 1950 stocks and stockings since 1950. The pre 1950 situation is fragmentary and rather vague in that locations mentioned in the literature and indeed verbal notifications hardly ever gave precise locations.

The distribution of the species around 1950 was limited to a few small ponds in the southern half of the country. Known locations included a small quarry at Dalkey in a private garden. This quarry was subsequently filled in and the carp rescued. A small pond 1 mile from Blackwater, Co. Wexford contained a breeding stock and most of the fish were stunted. A pond near Kilsheelan, Co. Tipperary also contained a breeding stock of stunted carp. However, in 1976 the latter two ponds dried up with consequent loss of breeding stock. A small lake near Clonmel holds a breeding stock and in 1977 a fish of 14.64 kg was captured by an angler and later returned alive to the lake.

In 1950 a guest house owner transferred some carp from the Blackwater pond in Co. Wexford to Ballinderry Lake near Moate, Co. Westmeath. In 1951 he also stocked the same lake with some 2 Y.O. carp imported directly from Germany. It was hoped that these fish would create a sport angling fishery. Subsequent to this the Inland Fisheries Trust, which had just begun to operate, took an interest in carp transfers with the idea of providing sport angling for the species. Details of all carp transfers carried out by the Inland Fisheries Trust are shown in Table 1. Also shown in the table are three stockings not carried out by the Trust. These include the two stockings to Ballinderry Lake mentioned above, and a third stocking of a pond near Ballina. The latter pond was stocked with young carp imported from England in 1974. The approximate locations of all known carp stockings are shown in Figure 1.

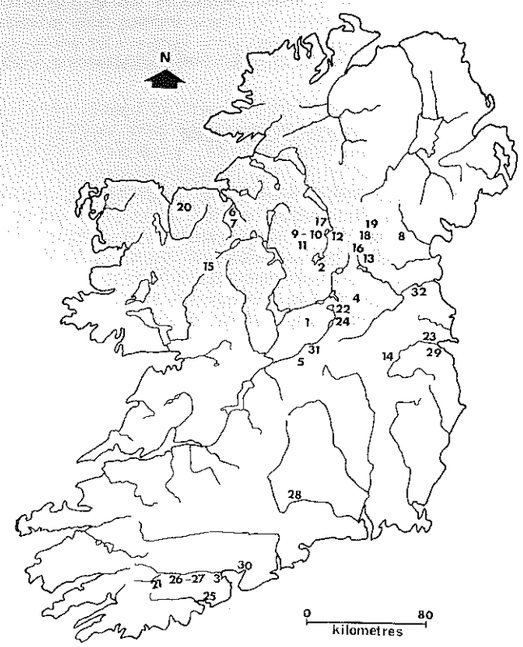

FIGURE 1. Locations to which carp were introduced since 1950. Numbered locations refer to Table 1.

VARIETIES OF CARP IN IRELAND

For many centuries carp have been selectively bred for specific characters such as fast growth and/or proportionately more flesh weight per carcass. The result has been the development of deep-bodied types of carp often partially scaled. These cultivated carp have frequently been stocked in lakes and ponds and have established breeding populations. Some of the offspring retain the body characters produced by artificial selection whilst others revert in a greater or lesser degree to the ancestral form.

There are four basic types which could be defined as:

(a) Fully scaled carp with fair sized scales which are covered by a normally pigmented epidermis and with the body deeper than the ancestral wild carp.

(b) Mirror Carp. Most of the body naked with a leathery skin. Some very large scales characteristically forming a row on either side of the dorsal fin, along the lateral line; sometimes a few large scales situated ventrally. Scales pigmented with silvery guanin.

(c) Leather carp. Scales almost entirely absent and skin leathery.

(d) A form which appears to be naked but which on close examination proves to have a full covering of very thin transparent scales. No pigment on the scales.

All four types were present in the Kilsheelan stock prior to the drying up of that pond. No other Irish waters are known to contain the full range of varieties although offspring from the Kilsheelan stocks have been transplanted into a number of waters. It is likely that these transplanted fish still retain the genetic characters capable of producing the four basic types.

Table 1. Irish waters into which carp have been introduced since 1950. Station numbers refer to location in Figure 1.

Station No.	Water Stocked	Origin	Date	Observations
1	Ballinderry	Blackwater Pond	1950	Now absent, transferred out of lake.
1	Ballinderry L.	Germany	1951	Stocked as 2 Y.O. approx. 10 oz.
2	L. Gowna	Dalkey Pond	1953	5 adults, average weight 5 lb.
3	The Lough, Cork	Kilsheelin/Fish Farm	1954/76/77	Grew to approx. 20 lb. 80 fish in original stocking.
5	Pond at Pallas Lake	Kilsheelan	1954	Now absent.
4	Reynella L.	Ballinderry L.	1956	Lake drained, carp transferred.
6	Ardrea L.	Kilsheelan/Fish Farm	1961	150 fish stocked. Now absent.
7	Ballinascarrow L.	Kilsheelan/Fish Farm	1961	150 fish stocked. Now absent.
8	Capra Lake	Kilsheelan/Fish Farm	1962	200 fish stocked. Now absent.
9	Green L. Killeshandra	Kilsheelan/Fish Farm	1962	200 fish stocked. Now absent.
2	L. Gowna	Kilsheelan/Fish Farm	1963	70-80, 2+ fish and small adults.
10	Town Lake, Carrickallen	Kilsheelan/Fish Farm	1964	250 fish stocked. Now absent.
11	Clooncorick L.	Kilsheelan/Fish Farm	1964	250 fish stocked. Now absent.
12	Killamooney L.	Kilsheelan/Fish Farm	1964	150 fish stocked. Now absent.
13	Drumlon L.	Kilsheelan/Fish Farm	1964	1 fish found in 1969.
14	Grand Canal, Prosperous	Kilsheelan	1964/73	Over 100 fish stocked. Now absent?
15	Cloonacurry L.	Kilsheelan/Fish Farm	1965	52 fish stocked. Now absent.
16	Town L., Bailieboro	Kilsheelan/Fish Farm	1965	63 fish stocked. Now absent.
17	Puttiaghan L.	Kilsheelan/Fish Farm	1965	50 fish stocked. Now absent.
18	White Lake Coothill	Kilsheelan/Fish Farm	1965	50 fish stocked. Now absent.
19	Derryvalley L.	Kilsheelan/Fish Farm	1965	50 fish stocked. Now absent.
20	Pond, 10 km E of Ballina	England	1974	40 small fish stocked, growth good.
21	Riordans Pond, Macroom	Kilsheelan/Fish Farm	1974/77	250 fish stocked.
22	Galmoylestown L.	Fish Farm	1975/76/77	1,400+ fish stocked, mainly 0+. Growth good.
23	Dog Pond, Phoenix Park	Fish Farm	1976	Present in 1977.
24	Doolin L.	Fish Farm	1976	Present. Growth fair.
25	Dunbogue L.	Fish Farm	1976	520 fish stocked, all 0+.
26	Back Road Pond, Macroom	Fish Farm	1976/77	22 adults in 1976, 94 stocked 1977, all 0+.
27	Dineen's Pond, Coachford	Fish Farm	1976/77	119 fish stocked, mainly 0+.
28	Kilsheelan Pond	The Lough/Fish Farm	1977/78	30+ adults stocked, spawning confirmed.
29	Herbert Park, Dublin	Fish Farm	1977	
30	Pond, Fota Island	Fish Farm	1978	250 fish all 2+. Growth good.
31	Cornaher L.	Fish Farm	1978	13 adults, drainage has affected this lake.
32	Taffe's Lake, Duleek	Fish Farm	1978	

Habitat and influence of carp on the ecology of waters

According to Tate Regan (1911), carp inhabit lakes, ponds and the sluggish reaches of large rivers. They can withstand lower dissolved oxygen levels than most other fishes (Varley 1967). However, a reasonable degree of oxygenation is desirable otherwise the fish may not be inclined to feed under other favourable conditions such as optimum temperatures.

Schaperclaus (1961) states that while carp can withstand freezing temperatures in winter, they thrive best where summers are warm. Huet (1960) states that the period of growth coincides with the warm season and that the optimum temperature for development is in the range 20°C to 25°C. He also states that below 13°C, growth is much reduced and the species cease to feed below 5°C. Schaperclaus (1961) suggests that maximum growth is made in July and August on the continent and that the average temperature is less significant than the number of days with water temperatures of over 20°C.

In Ireland carp thrive best in small lakes and ponds which are sheltered from cold winds. Other desirable features would include some deepish water for overwintering and shallow productive areas in which to feed. If the carp are to spawn regularly, shallow areas with emergent vegetation where water temperatures should attain high values early in the summer are necessary. However, if adequate numbers of carp can be stocked, breeding would not necessarily be important since a relatively small population of big carp can provide good angling.

Carp feed on or in the bottom mud. In feeding they stir up the mud and silt and in silty bottoms they can penetrate the silt up to depths of 12 cm. During this activity they uproot submerged and emergent vegetation and the waters tend to be continually turbid.

In the U.S.A. the introduction of carp is now regarded as an ecological disaster (Stroud 1975). The adverse effect of carp on the ecology of American waters has caused the disappearance of indigenous fish species. In many locations carp have become the dominant species. The ecology of these waters coupled with the temperature regime provided ideal spawning conditions for this species.

SPAWNING IN IRISH WATERS

Natural Spawning

The culture of carp cannot be practised except where the water becomes sufficiently warm early in the season (Huet 1970). Ruhmer (1952), Huet (1970) and Bourgeois (1962) all suggest that for spawning to take place, a temperature of 20°C is necessary during the months of April to June. It also appears that for a number of weeks before spawning, a water temperature in the range of 14°C to 17°C is necessary to induce ripening of the ova. Only during exceptionally fine summers are these water temperatures likely to be universally found in Irish waters. However in ponds such as Kilsheelan, which contained a breeding population of carp, water temperatures are constantly above average for the country. In 1966 during the months of May, June and July a comparison of marginal water temperatures showed that in Kilsheelan pond, the water temperatures were on average 2°C to 3°C higher than in either Lough Ennell or Lough Mask. The daily minimum temperatures were 3°C to 5°C higher in Kilsheelan pond. This would explain why carp breed annually in Kilsheelan pond and at very irregular intervals in other waters.

On three occasions in 1959, 1974 and 1976 accidental spawnings took place in holding ponds in Roscrea fish farm. These spawnings occurred in large earthen field ponds which resembled natural ponds. Carp were held in these ponds during the spawning seasons of other years but no spawnings took place because water temperatures failed to rise and meet the spawning requirement.

Artificial Spawning

Because a warm temperature of 20°C or over is needed for carp spawning and fairly warm conditions are necessary some weeks prior to spawning for ripening of the eggs, supplies of wild carp for stocking purposes are severely limited. Importation of carp is undesirable because of the risk of introducing diseases and parasites. The only other way of ensuring sufficient carp for stocking is by attempting to induce carp to spawn under artificial conditions.

During 1971 at the headquarters of the Inland Fisheries Trust in Dublin, attempts were made to spawn carp artificially. A shallow concrete pool with a depth of 30 cm. and measuring 8m × 3.75m was divided by a metal screen to separate males from females. This pool was fitted with a recirculating water system and a water filter. Two polythene lined ponds measuring 3m × 2m each were excavated inside a lean-to greenhouse. One pond was intended to act as a scaled down version of the classic Continental Dubisch pond as described by Huet (1970), having a central weeded plateau with a perimeter channel of 25 cm wide. The second pool was intended for fry.

In the period June 22nd to August 17th, eight experimental spawnings were attempted. The procedure carried out followed that adopted by continental fish farmers in that one female and two or three males were introduced to the Dubisch pond after the water temperature had risen above 20°C. In all, three successful spawnings occurred.

In each of the successful attempts spawning took place within 24 to 48 hours of the fish being put into the Dubisch pond. This is in agreement with experience in continental carp culture. Also, the spawnings began in the morning.

With regard to the failed spawning attempts there are three main reasons why they were unsuccessful. The fertility of the females was doubtful. The female spawning stock ranged from 1 kg to 3.75 kg and were originally salvaged from a pond in Dalkey. Scale examination showed that they were eleven to thirteen years old and it was unlikely that they had ever spawned in the cold waters of the quarry. No young carp had been found in the quarry. Two of the females which had failed to spawn were largely or partly infertile. Indeed there was reason to believe that some eggs shed in the spawning acts were not being adequately fertilized. The spawning pond, while it may have been suitable for small stunted fish, was almost certainly too small to provide suitable spawning conditions for the size of fish used. Also the failure of spawnings in August may be attributed to the fact that attempts were made too late in the year; at this time the females were beginning to resorb their ova.

The experiments showed that, under glass, it was possible to achieve spawning temperatures in ponds during the months of May, June and July. The actual differences made by the greenhouse can be seen by comparing the temperatures recorded in the outdoor conditioning pond and a pond in the greenhouse:

Table 2. Water temperatures (°C) recorded in outdoor conditioning pond and in greenhouse pond.

Month	May	June	July	August
Conditioning Pond	11—15	12—18	15—23	13—18
Greenhouse Pond	16—25.5	16—29	20—30	17—34

It is clear that by using a greenhouse or perhaps polythene covered frames over outdoor Dubisch ponds, controlled carp spawning should be possible during an average Irish summer.

GROWTH

Schaperclaus (1961) refers to observations by Einsele on sixty carp of known age. Of these, seven were 43 years old. At 37 years of age some carp weighed up to 30 kg.

In 1954 a party of anglers transferred approximately 80 carp, in the size range 12 cm to 17.5 cm, from Kilsheelan pond to the Lough in Cork city. Average weight on transfer was 50 to 70 g. In early 1959 a sample of netted fish ranged in weight from 2.3 kg to 3.7 kg. This represents an average annual weight increment of 0.5 kg to 0.75 kg. If left in Kilsheelan these fish would at most have weighed 1 kg and would possibly weigh as little as 0.25 kg. The maximum recorded weight of a Kilsheelan carp was 1.6 kg.

Carp spawned by stunted Kilsheelan parents on Roscrea fish farm in 1959 grew to approximately 1 kg at 2+ in 1961. Two subsequent spawnings on the fish farm showed similar growth rates. Stockings of carp from the latter mentioned spawnings were carried out in 1975, 1976 and 1977 and fish were placed in Galmoylestown lake near Mullingar. By 1979 the carp had grown to a maximum of 5 kg, the average weight of 35 fish being 1.5 kg.

In June 1978, 250 small carp aged 2+ and weighing on average 80 g were stocked in a pond on Fota Island. By mid September of the same year they were averaging 0.49 kg and when sampled again in mid January, 1979, the average weight of 31 fish was 1.1 kg.

The stunting of the Kilsheelan carp is an environmental factor rather than a genetic one. This is evident from the growth rates obtained after direct transfer into other waters and also from the growth obtained when offspring, which were produced at Roscrea fish farm, were stocked into Galmoylestown lake and Fota Island pond.

DISCUSSION

The carp is a cyprinid which has been introduced into Ireland since the 1600's. Because of the relatively high water temperature needed for spawning it is essentially adapted to a continental climate with high summer temperatures. The differences in the pattern and seasonal temperature ranges between Ireland and the Continent affects the reproduction of the carp. In only two locations were carp known to reproduce on a regular basis. These two ponds, being small in area and shallow, dried up during the dry summer of 1976 with subsequent total loss of all spawning stock. Since then one of these ponds (Kilsheelan) has been restocked with carp and a natural spawning has been confirmed.

The status of carp as a permanent member of the Irish freshwater fish fauna is very precarious and if stockings had not been carried out since 1950 it is doubtful if the species would now be part of our fish fauna. Experiments in carp culture were successfully carried out showing that it is possible to culture carp under Irish conditions. The main factor involved here is having adequate water temperatures of 20°C in May, June or July to ensure spawning.

Although summer water temperatures in Ireland are much lower than that of the Continent, the growth rate of carp in the wild is quite good and growth to over 14 kg has been recorded. Carp grow best in waters where there are no predators or competitors and which are rich in invertebrate foods.

In Ireland there is no commercial fishery for coarse fish. It is solely as an angling species that any coarse fish must be evaluated. Coarse angling tourism is now worth in excess of eight million pounds in external revenue to Ireland and with comprehensive breeding and stocking it should be possible to create and maintain good quality carp angling.

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Migratory patterns of bream *Abramis brama* L. shoals in the River Suck System

by

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ABSTRACT

Yearly revenue from coarse fish angling tourism in the River Suck Catchment is currently (1980) valued at £320,000. Future bog development in the area may pose a threat to the feeding and spawning behaviour of the principal angling species, the bream, *Abramis brama* (L.). An intensive Floy tagging programme was carried out on the River Suck during the past five years to trace the natural movements of bream shoals. A total of 2,763 fish were tagged of which 110 or 4% were subsequently recaptured. Distinct spawning migrations have been traced over several years and individual fish have migrated up to 59 km. Survival of tagged fish is exceptionally high and to date recaptures have been recorded after 1,437 days at liberty.

INTRODUCTION

In the spring of 1975, Bord na Mona commissioned the Inland Fisheries Trust to carry out a comprehensive biological and chemical survey of the River Suck and its tributaries and to monitor the effects of proposed peat bog development on the system. To date four reports on the River Suck have been completed and a fifth is in preparation (Whelan 1976, 1977, 1978, 1979 and 1980).

The River Suck is a large slow flowing river characterised by long stretches of deep water alternating with short sections of a more streamy fast flowing nature. Depths of up to 10m are present and the river can at times exceed 100 metres in width. The river is alkaline with a normal pH range of 7.8 to 8.2. The marginal areas are productive and contain abundant floral and faunal populations. The main River Suck is one of the principal Irish river coarse fisheries. It holds a dense stock of bream *Abramis brama* (L.), rudd *Scardinius erythrophthalmus* (L.), pike *Esox lucius* (L.), and perch *Perca fluviatilis* (L.) and fair stocks of tench *Tinca tinca* (L.).

Angling tourism is an important asset to the catchment and during the past year 1,600 anglers visiting the area spent an estimated £320,000 (Whelan, 1980).

The large resident bream shoals present in the River Suck are the principal quarry of the visiting angler. A total of 2,763 bream has been Floy tagged since May 1975 and it has been possible to trace the natural movements and migrations of these fish. The present paper outlines the results of this tagging programme.

MATERIALS AND METHODS

A variety of methods were used to capture the bream for tagging. The original samples were taken from the shallow water using Onan 250 volt petrol generators. The generators used DC current inducing galvanotaxis and drawing the fish towards the anode. These samples were batch tagged using colour Floy tags and released. This method was found to be unsatisfactory in that individual fish could not be identified, the electrical fishing was only fully effective in waters less than 2 m deep and the method was also labour intensive.

In the second year of the study angling-caught samples of bream were used. Linfield (1980) has also found this method of sampling to be effective in coarse fisheries. Certain areas of the river were initially treated with ground bait to attract the bream shoals and visiting anglers were encouraged to fish these pre-baited areas. All fish caught were collected at the end of each day and held in large keep nets, 45 cm in diameter and 3.7 m long. The bream were measured and those above 22 cm were tagged using a number coded Floy tag. Mature bream were sexed externally according to the features described in Kennedy and Fitzmaurice (1968). The rough texture of the skin and raised tubercles on the head, back and shoulders identify the males during the spawning season.

Recaptures of tagged fish were recorded from angling returns, gill netting and fish trapping surveys.

RESULTS

A total of 2,763 bream have been Floy tagged and released into the River Suck. Of these 1,447 were batch tagged using colour coded tags and a further 1,316 were tagged with individually numbered Floy tags. In total 42 (3%) coloured Floys and 68 (5%) numbered Floys were recaptured, giving an overall recapture rate of 4%. The bream were tagged at 10 sites along a 60 km stretch of the main River Suck (Figure 1). Of the 110 bream recaptured 35 were recorded at 2 km to 59 km from the original tagging site. The remaining 75 (68%) were recaptured on site.

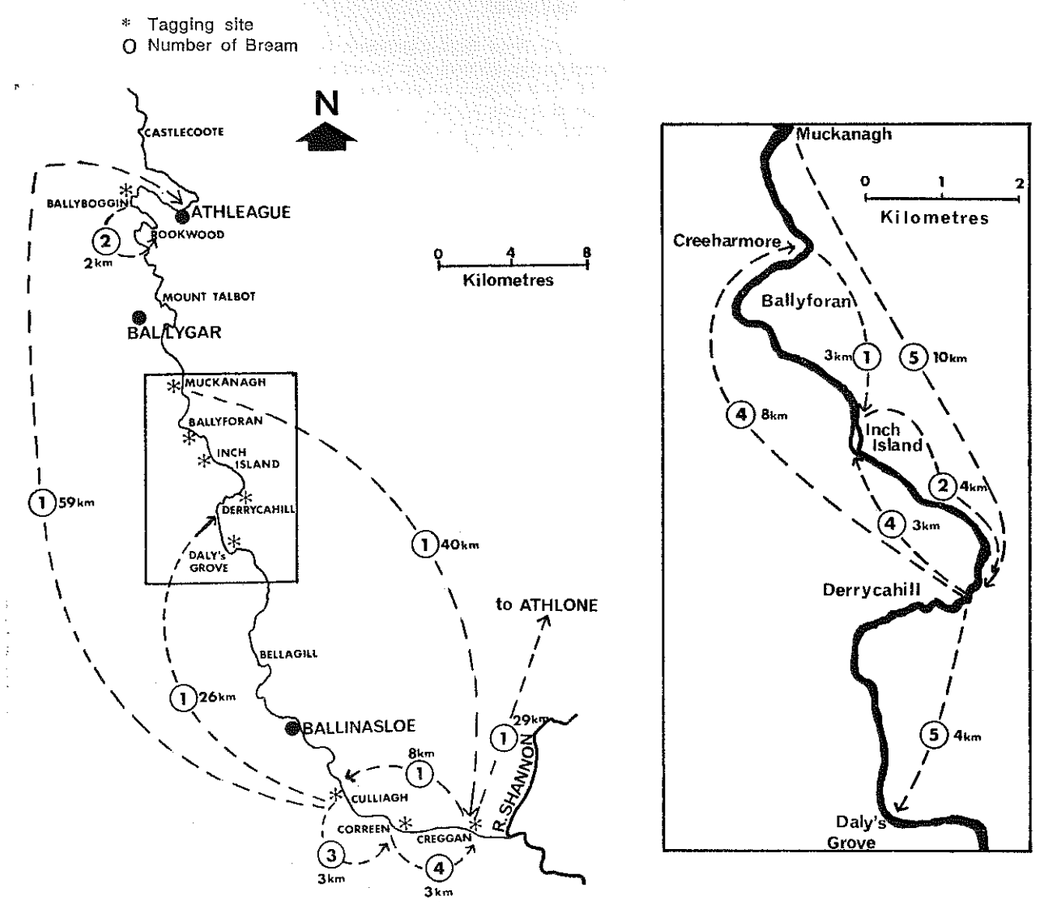

FIGURE 1. Bream movements in the River Suck system.

The period between tagging and recapture ranged from 0 days (caught within one day of tagging) to 1,437 days (Table 1). The majority of fish were captured within one year of their release. The greatest number of recaptures were made each year during the bream spawning period, mid-May to mid-June, when angling pressure was greatest. This fact is reflected in the results where peaks of recaptures occur after 0-100, 300-400 and 700-800 days at liberty (Table 1).

Since the tagging and recapture sites were located at 10 points along 60 km of river it was possible to trace the migration of bream shoals and the movement of individuals over a period of 5 years. Both upstream and downstream movements were recorded.

Four bream displayed exceptional movement and travelled distances of 56 km, 40 km, 29 km and 26 km. One of these bream travelled from the River Suck to the River Shannon and upstream to the "meadows" angling stretch at Athlone. The majority of bream appeared to remain within their respective shoals which displayed regular spawning migrations of up to 10 km. The study to date has located three spawning sites at Derrycahill, Culliagh and Creggan. Large shoals of bream are also frequently observed at spawning time in the vicinity of the River Suck and River Shannon confluence at Shannonbridge. It is not yet known whether these aggregates include bream from both river systems or shoals from only one of the rivers.

The migration pattern of bream shoals to and from the spawning site at Derrycahill has been observed over several years and it is now possible to trace the migrations of the four shoals which form the spawning aggregate. There is a resident Derrycahill shoal, a shoal which moves upstream from Dalys Grove and two shoals which migrate downstream to spawn, one from the Ballyforan/Inch Island area and one from the Muckanagh/Creeharmore area. Population estimates carried out on the spawning aggregates of bream at Derrycahill have shown that as many as 4,000 bream over 22 cm may be present at any one time (Whelan, 1977).

During the three spawning seasons of 1978, 1979 and 1980 a total of 208 mature female and 128 mature male bream were recorded. The male to female sex ratios were 1 to 1.7 in 1978, 1 to 1.4 in 1979 and 1. to 1.8 in 1980. The overall ratio of mature males to females was 1 to 1.6. These results show a predominance of mature female bream in the rod caught samples examined. Kennedy and Fitzmaurice (1968) and Backiel and Zawisza (1968) also noted that females predominated in the older age groups.

Table 1. The period between tagging and recapture of River Suck bream shown in days and approximate calendar years.

	Days	Percentage Recapture	Cumulative Percentage Recapture
1 year at liberty	0 - 100	36%	
	100 - 200	7%	
	200 - 300	4%	
	300 - 400	20%	67%
2 years at liberty	400 - 500	11%	92%
	500 - 600	1%	
	600 - 700	2%	99%
	700 - 800	11%	
3 years at liberty	800 - 900	2%	
	1,100 - 1,200	5%	100%
4 years at liberty	1,400 - 1,500	1%	

DISCUSSION

Backiel and Zawisza (1968) describe in detail the biology of the bream in many of the larger European rivers and lakes. In most waters these fish are semi-migratory. In the case of the Caspian bream the spring migration begins with the melting of ice on the sea. The first group of bream start their upstream migration at the beginning of April while the second and larger run, lasting for 15-20 days starts only when the water temperature has reached 8°C. After spawning, the bream return to the sea and disperse to feed. In the Dneper River two migrations take place. The "winter" bream migrate up to 100 km upstream while the spring fish occur in the lower reaches of the river. A tagging programme in Lake Sniardwy, Poland showed that a distinct aggregation of separate feeding shoals took place on a definite gathering ground in winter and these fish subsequently migrated to their

spawning grounds in spring. Gaygalas and Blatnene (1971) also note that the bream of the Nyamunas River delta enter the summer embanked polder systems only during the spring flood which usually begins at the end of March or in the first half of April. Astrauskas (1971) marked 530 bream in the cooling reservoir of the Lithuanian Hydroelectric Power Station. Some of the tagged fish were transplanted to other areas but all of these were recaptured at the same spawning, feeding or wintering grounds where they had been taken for marking. The author recorded an overall recapture rate of 6% for the 2 year study.

Astrauskas (1971) concluded that each local population has its own spawning grounds and definite feeding, overwintering localities. The marking of feeding populations showed that part of the population ascended into the river reach late in the autumn and overwintered in the areas of the spawning grounds while other fish from the same population moved to the spawning grounds in spring immediately before spawning. Goldspink and Banks (1971), Goldspink and Banks (1975), Goldspink (1978a) and Goldspink (1978b) describe a tagging programme carried out on Tjeukemeer in the Netherlands. A total of 16,690 tagged bream were introduced into the lake with a subsequent recapture rate of 7.4% for fin clipped fish and 5% for opercular tagged fish was recorded. Of the 452 recaptures 351 were in the lake while 101 were in the general catchment outside the lake. Goldspink (1978b) concludes that bream are semi-migratory and have a limited ability to home.

The general movement of the bream shoals within the River Suck system follows a pattern similar to that described for other European waters. Following spawning, the aggregates disperse into separate shoals which migrate to their respective feeding areas and here they display seemingly random localised feeding movements. Gill netting surveys carried out on the main river indicate that feeding shoals rarely travel further than 2 km within their feeding zone and that feeding fish are most active during periods of settled warm weather. Feeding becomes sporadic during mid to late October and the shoals display little activity until late March to mid-April when they migrate towards their spawning site. The homing instinct of the River Suck bream is strong and active spawning migrations take place both in an upstream and downstream direction.

The purpose of the long distance migrations undertaken by a small proportion of those bream tagged is still unknown. However, several other authors have also noted that a minor proportion of bream populations may move long distances while the majority display only localised migrations (Backiel and Zawisza 1968, Goldspink 1978a). The latter author quotes the results from Lipno reservoir where 88% of all marked fish were recaptured within 1 km of the release point. In the present study 68% of recaptures were made within 1 km of the tagging site.

ACKNOWLEDGEMENTS

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The impact of arterial drainage on fish stocks in the Trimblestown River

by

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ABSTRACT

The impact of arterial drainage works on the fish stocks of the Trimblestown River, a tributary of the River Boyne, are described. A change in fish species from predominantly salmonids to small riverine coarse fish species was observed. The impact of arterial drainage on the wild salmon stocks of the Boyne Catchment is also described. Proposals to ameliorate the effect of arterial drainage of salmonids in future drainage works are outlined.

INTRODUCTION

The land mass of Ireland is saucer shaped with a high maritime rim and flat interior. Many of our rivers have poor gradients resulting in river flooding and poor land drainage. A moist humid climate and low evaporation are contributing factors. Many countries have rainfall and run off higher than Ireland but these areas are usually saved from land drainage and flood problems by their local physiography. In the past 25 years arterial drainage works have been undertaken on many of our best salmon rivers, the Corrib, Feale, Moy, Boyne and Maigue catchments.

Many environmental impacts are associated with drainage: increased nutrients, loss of aquatic habitat, loss of habitat diversity and change of riparian habitat. These can also have a synergetic effect on the rate of recovery of salmonids in a post drained river. Furthermore, arterial drainage is a continuing process: once started it must be followed up by post drainage maintenance on a regular basis to be of benefit to the adjoining land. Hardly has a river recovered or partially recovered from the trauma of the initial dredging than it is subjected to further arterial works.

Some rivers are disturbed more than others depending on the amount of regrading required to be done to effect satisfactory run off in times of flood. Increased turbidity and downstream sedimentation vary depending on the soil type of a catchment. To give just two instances, bed type may alter from gravel to bed rock or from peat to gravel. The composition of the indigenous fish species is also of fundamental importance. Rivers that contain only salmonid species would appear to have a better rate of recovery than rivers which contain salmonids and small riverine coarse fish species such as stone loach *Nomacheilus barbatula* (L.), minnow *Phoxinus phoxinus* (L.), gudgeon *Gobio gobio* (L.) and stickleback *Gasterosteus aculeatus* (McCarthy, 1975).

The impact of drainage, channelisation and excavation works on fish and the food of fish have been studied in Ireland on the River Moy (Toner, O'Riordan and Twomey, 1965) and on the River Boyne (McCarthy, 1975, 1977). This paper gives details of changes in the fish populations of a tributary of the Boyne resulting from drainage, discusses the impact of drainage and makes recommendations for measures to be taken to reduce the adverse effect of drainage on salmonid stocks.

STUDY AREA

When the proposed arterial drainage scheme was announced for the Boyne System, it was decided to undertake a detailed pre and post-drainage survey of the invertebrate fauna, fish stocks, flora, physical and chemical parameters of one of the tributaries to be drained. The River Boyne rises south east of Edenderry and flows east for 112 km to the sea at Drogheda on the east coast of Ireland. It has fifteen major tributary streams and two lakes in its catchment area of 2693 km^2. A site on the Trimblestown River, one of the major tributaries, was selected. The Trimblestown rises at the foot of Slieve na Cailliagh at an elevation of 150m and flows 35km southeast mainly through pasture to join the main river at the town of Trim. Rocks of the basin are Middle and Upper Carboniferous limestone overlain by lime-rich glacial drift. The area chosen was 246 m long and averaged 6.1m in width, with alternate riffles and pools. The bottom was stony and in places overlain by silt. There was abundant submerged and emergent aquatic vegetation. Banks were grassy and sloped gently for approximately 1 metre to the river. Tree cover was extensive. The study commenced in the autumn of 1968, four years prior to drainage in 1972 and continued until the winter of 1974, two years and eight months after drainage works were completed on the site.

RESULTS

Fish stock pre drainage

A series of electro fishing surveys in 1968, using the De Lury (1947) method of fish stock assessment, established the site as a salmonid nursery with a large population of brown trout *Salmo trutta* L. and juvenile salmon *Salmo salar* L. Other resident fish species were:— eels *Anguilla anguilla* (L.), stickleback and stoneloach. The total population was estimated at 638 fish, density 0.73/m^2 and a biomass of 18.2 g/m^2. The sample was composed of:— 432 brown trout, 163 juvenile salmon, 20 eel, 14 stickleback and 9 stone-loach. The ratio of salmonids to other fish species was approximately 14 : 1.

The brown trout sample was composed of 232, 0 group and 200 of one to four years of age. The mean length and weight of the 0 group were 6.5cm and 4.2g. Trout of age one to four years had a mean length of 15.7cm and a mean weight of 58.0g. There were four 4+ in the sample and these varied from 184 to 248g. Of the 163 juvenile salmon collected, 20 were 0-group salmon with a mean length 6.1cm and weight of 3.0g. The remainder of the salmon were 1+ with a mean length of 11.4 cm and a mean weight of 20.2g. Of the 1+, 55% were maturing males; no 2+ were present in the sample. The Boyne system has a predominantly 1+ smolt class with the remainder migrating as 2+. Table 1 gives the density and standing crop in g/m^2 of the various fish groups in the sample.

Drainage

The action of the dredgers is to dig out the rocks, soil and gravel of the river bed to a predetermined depth by means of a drag-line and bucket. The spoil is then deposited on the banks.

The bed of the river or the substratum is the layer where insect life predominates and in the process of drainage this layer is taken away and with it the majority of the stream invertebrates. However a number of invertebrates escape the dredger and drift downstream but the actual number is difficult to determine in silt-laden water. Drainage was completed on the stream section under review in March 1972 and on the whole river the following June. The bed level was lowered 1.5 metres in the study area and the mean width of the stream was increased from 6.1 to 6.8m. Bank height increased from 1.0 to 2.9m, and the banks were quite steep, unlike the rounded gently sloping banks prior to drainage. River flow which was calculated at 0.77 cubic metres per second in September 1968 prior to drainage had increased to 0.83 cubic metres per second under normal flow conditions. Suspended silt levels were very high during and after drainage. These ranged from 945 to 1889 ppm.

Fish stocks post-drainage

In May 1974, two years after drainage, the area was electro-fished. A total of 316 fish were removed; of these 156 were stoneloach, 135 minnow, 15 brown trout, 6 gudgeon and 4 stickleback. The ratio of coarse fish to brown trout was 33 : 1, no juvenile salmon being caught. The density of fish in the study area was .032/m^2, a drop of 0.38/m^2 on pre-drainage stocks. The biomass was also low, 3.27 g/m^2 against 18.2 g/m^2 prior to drainage. Six of the brown trout were 1+, five were 2+ and four were 3+. No fry of the year were captured. The average length and weight were 20.0cm and 133g.

However a return of salmonids was recorded in fishings carried out in November 1974. A total of 415 fish were removed from the area: 51 juvenile salmon, 15 brown trout and 345 stoneloach, minnow and stickleback, all the salmon were 0+ and were the progeny of salmon which had spawned in the area in 1973/74 spawning season. The ratio of coarse fish to salmonids was 5 : 1 which was an improvement over the May census. The brown trout were composed of nine 0+ fsh, two 1+ and four spent males, two of these were 2+ and two 3+. Details of species density and biomass are given in Table 1.

DISCUSSION

The change in the Trimblestown River site from a salmonid nursery stream to a predominantly small coarse fish habitat is in stark contrast to the results obtained by Toner, O'Riordan and Twomey (1965) on the River Moy. The contrast is not in the rate of recovery of the invertebrate fauna but in the rate of recovery of salmonid fish in the drained streams. This is not surprising as each catchment must be taken as a separate unit and no general conclusions can be drawn on the impact of arterial drainage works on the rate of recovery of fish stocks and the food of fish.

Suspended solids at the levels monitored during and after dredging activities on the site (1889-945 ppm) are not sufficient to kill adult trout and salmon parr, however growth and resistance to

disease are affected by these levels (Alabaster and Lloyd, 1980). Stuart (1953) has shown that salmon and trout eggs—which are buried in gravel on the stream bed can develop successfully only if a current of water passes through the gravel, he further found that brown trout do not dig redds in gravel if it is choked with sediment. Campbell (1954) planted eggs in gravel in Powder River, Oregon where turbidity was between 1000 and 25000 ppm. All the eggs died within six days although there was only a 6 per cent mortality in 20 days at a control site where the water was clean. Following drainage of the Trimblestown River sedimentation of the river bed to a depth of 30cm occurred affecting salmonid spawning, submerged vegetation and the production of aquatic invertebrates.

Apart from the studies outlined on the Trimblestown River site, fish stock assessment studies have been undertaken on all major tributaries of the Boyne Catchment. This work is still in progress.

Rivers which were drained during the first phase of the Boyne scheme in the early seventies are showing little sign of recovery. They all have very small numbers of young salmon most of which are stocked fish. The recovery of the brown trout population in these rivers is good however and continuing at a steady pace. It has been estimated that the natural salmon stocks of the Boyne Catchment were dependent on the smolt production of a single river, the Blackwater, where smolt production in 1978 was calculated at 23,000 (John Browne, pers. comm.). However arterial works are now in progress on the Blackwater and it is feared that the impact of dredging on this river will reduce further the rate of recovery of salmon in the Boyne Catchment.

Table 1. Density and biomass of the fish population in the study area of Trimblestown River.

Species	Pre-drainage September 1968			Post-drainage 1974		
	Numbers	Numbers per m^2	Weight (g) per m^2	Numbers	Numbers per m^2	Weight (g) per m^2
Brown trout 0+	232	0.26	0.94	0		
Brown trout 1+ to 4+	200	0.22	12.95	15	0.015	2.0
Salmon 0+ to 1+	163	0.18	2.64	0		
Eel	20	0.02	1.7	0		
Gudgeon	0			6	0.006	0.1
Minnow	0			135	0.14	0.67
Stoneloach	9	0.01	+	156	0.16	0.5
Stickleback	14	0.016	+	4	0.004	+
Total	638	0.70	18.2	316	0.32	3.27

CONCLUSIONS

The Boyne Catchment with its heavy overburden of argillaceous clays has suffered far more severely than the Moy from silting and downstream sedimentation.

The salmon restocking programme initially designed on the release of reared autumn fingerling was a failure due to the extremely low survival of the stocked fish.

The presence of large populations of small predatory coarse fish species in the drained streams has impeded the re-establishment of wild salmon stocks.

In the future it is considered that new design criteria should be established to reduce environmental disruption. Alternative channel designs as proposed by Keller (1975) could be incorporated as an experiment into the design stage of new arterial drainage schemes to test their effectivness in facilitating morphologic stability.

Salmon restocking programmes should be designed to take account of the indigenous fish species. When small coarse fish species are present, stocking should take place at the pre-smolt stage.

The presence of technical personnel on site to help and advise arterial drainage engineers on a daily basis can help to reduce the adverse environmental impact of drainage by the retention of tree cover, hand clearance of small spawning streams and the seasonal work in sensitive salmon nursery areas.

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Some observations on salmonid ecology in upland streams

by

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ABSTRACT

The survival of salmon stocked as eyed ova in upland trout streams was found to be lower when salmon parr were already present than when trout alone made up the resident fish population. The survival of salmon stocked as fry was also found to be lower close to an impassable stream barrier where much trout spawning took place. Trout fry survival was not affected by the presence of salmon fry, but was reduced by the presence of salmon parr. The results are discussed in terms of behaviour and the habitat preferences of each age of the two species.

The major regulator of population size in some fish species is considered to be compensatory mortality in the juvenile stages (Ricker, 1954). In salmonids this is known to be density dependent, and is likely to be greatest between fish occupying the same habitat (McFadden, 1968). Although investigations have been carried out into many species of co-habiting salmonids, the extent to which this interspecific competition regulates the densities of sympatric salmon *(Salmo salar* L.) and trout *(Salmo trutta* L.) has not yet been fully resolved. Le Cren (1965) recorded that the survival of trout fry was dependent only on the densities of trout fry present, whereas the survival of salmon fry was dependent on the density of both trout and salmon stocked in screened sections of a small stream. However, Gee, Milner, and Hemsworth (1978) maintained that the mortality of salmon fry was directly related to salmon fry densities and not 'co-existing species' under conditions of natural spawning in the River Wye.

The work described by Kennedy and Strange (1980) provided some indication of the effects of competition on survival between stocked salmon and naturally spawning trout in two upland streams in the River Bush catchment in Northern Ireland. The streams were isolated from natural salmon recruitment by a reservoir, and brown trout were the only resident fish species prior to the experiment. Eyed salmon ova were stocked out at a fairly high density of approximately 6 m^{-2} in artificial redds in two successive years, and survival and biomass were assessed annually by electrofishing. This work did not demonstrate any unequivocal influence of the introduced salmon fry on trout fry survival (see Figure 1). However, substantial declines in the trout fry populations were recorded in both streams following the second introduction of salmon. The inference is that although salmon fry do not affect trout survival, as recorded by Le Cren (1965), the presence of salmon parr does cause a reduction in trout fry stocks.

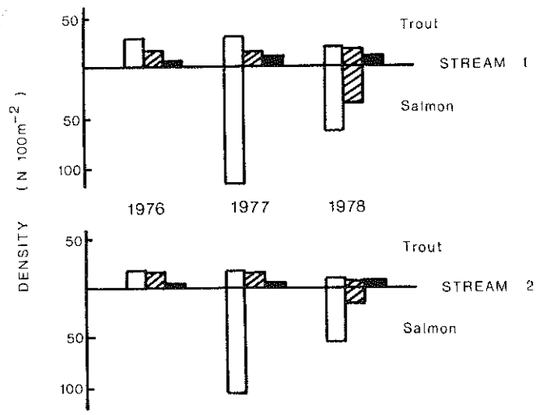

Figure 1. Mean population densities of trout and stocked salmon (numbers 100m—2) in two streams in the River Bush catchment during March 1976, 1977 and 1978. (0+: open; 1+: hatched; 2+ and older: black).

One of the major findings of Kennedy and Strange (1980) was that the survival of salmon fry in the presence of salmon parr was only about half that recorded when trout alone made up the resident stock (see Figure 1). Variation in salmon fry survival has not previously been ascribed directly to the presence or absence of salmon parr. Mills (1964) reported variation in the survival of planted salmon fry, and noted that predation by salmon parr on fry can occur. Symons and Heland (1978) confirmed this observation, but in stream tank experiments also noted that these two age classes interact territorially. These workers reported that fry of less than 6 cm were actively chased by parr and limited in their distribution while larger fry became involved in territorial disputes with parr. Kennedy and Strange (1980) note that they have not recorded a single incident of predation by salmon parr on fry, and they consider that competition for space is a much more important limiting factor.

Work by Kennedy (1980) has also provided evidence of the effects on salmon fry survival of competition for space with trout fry. Stocking of salmon 'swim up' fry at a density of approximately 6 m^{-2} was carried out during May 1980 over a 500 metre stretch of one of the upland trout streams used in the earlier experiments. The top of the stretch was delimited by an impassable fish barrier, and trout were free to migrate upstream from a reservoir as far as this barrier. Care was taken to distribute the salmon fry evenly over the whole area. However, when sites were electrofished over the length of the stocked area during August and September 1980 it was found that there was a highly significant ($p<.001$) downstream trend for increasing abundance of salmon fry relative to trout fry abundance (see Figure 2). This trend was non-linear, and a quadratic regression gave a significantly better fit to the data ($p<.01$). Neither the trout fry themselves, nor any of the older fish present, showed any significant density trends over the length of the stocked area. However, Kennedy *(op. cit.)* points out that many adult trout spawned in the upstream end of the stocked area after their spawning migration was blocked by the impassable barrier. Many more trout fry would therefore have hatched out directly downstream from the barrier than could possibly acquire territories and survive. Kalleberg (1958) has pointed out that in interspecies territorial disputes trout tended to be more successful than salmon. It is likely therefore that during the first few critical weeks of establishing territories the salmon in the upstream end of the stocked area were under much greater pressure from the large numbers of emerging trout fry in that area than were the salmon stocked further downstream. Downstream dispersal in this environment was found to be very limited (Kennedy, *op. cit.)* and competition for space from large numbers of trout fry directly below the barrier has therefore had a very localised influence on salmon fry survival.

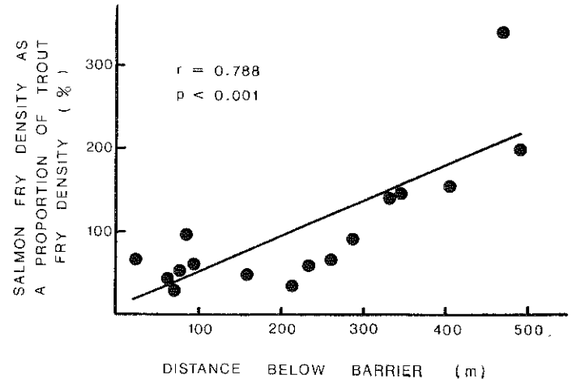

Figure 2. Densities of stocked salmon fry expressed as percentages of trout fry densities at sites in a 500m stretch below an impassable stream barrier during August and September 1980.

Kennedy and Strange (1982) have assessed the extent of competition between salmon and trout of different age classes by quantifying their habitat preferences when living sympatrically. In this case, sampling of the fish population densities in the upland streams was carried out by enclosing, as far as possible, one depth related habitat type at a time with stop nets i.e. deep pool, shallow pool, riffle etc. Water depths were measured on a grid system at each site. The results indicated significant correlations of density with water depth. These are illustrated in Figure 3 as the density of each age class in each depth range expressed as a percentage of the overall abundance of that age class. Fry of both species were highly significantly more abundant in shallow water sites than in deeper sites ($p<.001$). 68.3% of the salmon fry and 55.6% of the trout fry were captured in sites

of mean depth less than 20 cm. The older trout were highly significantly more abundant in deeper water ($p<.001$), with only 6.3% of these being captured in sites shallower than 20 cm mean depth. The yearling fish showed an intermediate relationship, being found in all the depth ranges sampled, but with a tendency for higher numbers in mid-range depths—significant in the case of trout. There were similar correlations in the abundance of each age class with the actual areas of shallow, mid-range and deep water habitat available within sites.

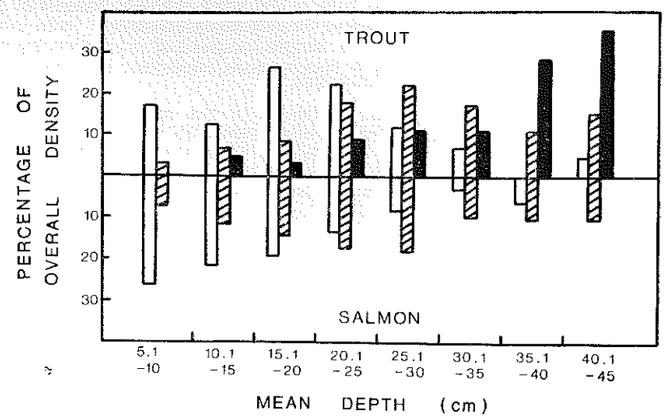

Figure 3. Population densities of each age class of salmon and trout captured in various depth ranges, expressed as a percentage of their overall abundance, in two streams in the River Bush catchment during August and September 1977. (0+: open; 1+: hatched; 2+ and older: black).

These distributions represent the extent of habitat overlap when two species are living together. However, as pointed out by Nilsson (1967), two fish species living sympatrically may adjust the niches they occupy as a result of competition, while their habitat preferences may be quite different when living allopatrically. It was found that the introduction of salmon could increase the standing crop in trout streams by one third and this was taken as evidence of allopatric niche selection (Kennedy and Strange, 1980). Kennedy and Strange (1982) confirmed that yearling trout were apparently limited in their distribution by faster water flows while salmon parr were not. However, the extent to which older year classes limited the distribution of fry, and the effects of interspecific fry competition on habitat distributions have not yet been quantified, and are the subject of continuing investigation.

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Parasites of salmon *Salmo salar* L. and trout *Salmo trutta* L. in the River Shournagh

by

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ABSTRACT

Monthly samples of salmon and trout were collected from a site on the River Shournagh, Co. Cork, during 1980. The fish were examined for parasitic infections and their diet was determined by analysis of stomach contents. Monthly faunal samples were also taken from the benthos to determine the abundance of invertebrate food.

Four main species of parasite were found to occur: *Crepidostomum metoecus* (Braun, 1900) (Trematoda), *Cystidicola farionis* Fischer, 1798, *Rhabdochona* sp. (Nematoda), and *Pomphorhynchus laevis* (Müller, 1776) (Acanthocephala). In the case of all four parasites, infestations of fish resulted from predation on benthic macroinvertebrates bearing the larval stages.

The seasonal variations and interspecific differences in parasitization were considered in relation to the fluctuating feeding habits of the salmon and trout. The influence of host age on the parasite burden was assessed. The differing site selection of the parasites was noted.

INTRODUCTION

An investigation into the fish parasitocoenosis of the River Shournagh, Co. Cork was initiated in 1980. While studies of the ecology of freshwater fish parasites have been made in many countries, little work of this nature has previously been carried out in Ireland. This paper reports the seasonal variations in infections of four species of parasite in salmon and trout during 1980. The parasites, *Crepidostomum metoecus* (Braun, 1900) (Trematoda), *Cystidicola farionis* Fischer, 1798, *Rhabdochona* sp. (Nematoda), and *Pomphorhynchus laevis (Müller,* 1776) (Acanthocephala) have all been recorded in Ireland (Kane, 1966) but their ecology in Irish freshwaters has not previously been investigated. The seasonal variations in parasite infections are examined against a background of the seasonal availability in the benthos of the macroinvertebrates which carry the larval parasites, and the feeding by salmon and trout on them.

MATERIALS AND METHODS

The River Shournagh, a tributary of the River Lee, rises in moorland to the north-west of Cork City and flows through agricultural land overlying Old Red Sandstone for most of its twenty-five kilometre course.

During 1980 eleven monthly fish samples were electrofished from a 50m stretch of the river (Grid ref. W581 765); continuous spate conditions prevented sampling in December.

Sex, weight and length of fish were recorded and fish age was determined by scale reading. Fish were screened in detail for parasites which were removed and preserved after the site of infection had been noted. The site occupied by parasites within the intestine was expressed as a percentage of intestinal length from post-pyloric caecae to rectum (Crompton, 1973), giving ten 10% sites. Permanent mounts were made of all parasites found. The incidence of infection, referring to the percentage of a fish sample infected with a parasite species, and the intensity of infection, referring to the mean parasite burden of infected fish, were calculated.

In order to establish the fish diet, the stomach contents were removed and the organisms present were identified and counted. The composition of the diet was analysed using the "occurrence" and "numerical" methods. The occurrence method counts the number of stomachs containing individuals of a food category and expresses it as a percentage of all stomachs with food. The numerical method counts the numbers of individuals of a food category from all stomachs and expresses it as a percentage of all food items from all stomachs.

To determine the macroinvertebrate food available to the fish community, monthly kick samples (Frost, Huni and Kershaw, 1970) were taken from the river benthos. The organisms were identified and counted. The findings for a particular species were expressed both in terms of actual numbers taken and their percentage of the total fauna (% abundance).

Invertebrate groups suspected of being intermediate hosts, primarily Ephemeroptera and Crustacea, were examined for the presence of larval parasites.

RESULTS

Fish Samples

Salmon and trout were the dominant fish species in the river, but eel, *Anguilla anguilla* (L.), and stone loach, *Noemacheilus barbatulus* (L.), also occurred.

A total of 188 salmon and 242 trout were examined in 1980. Table 1 shows the numbers and age composition of the monthly fish samples. Four age classes of trout (0+ — 3+) and three age classes of salmon (0+ — 2+) occurred, although they were not all present throughout the year: the 0+ fish did not appear in catches until mid-summer, and most 2+ salmon had smoltified and run to sea by May.

Table 1. The age composition of salmon and trout samples.

1980	TROUT					SALMON			
	All Ages	0+	1+	2+	3+	All Ages	0+	1+	2+
January	11	—	9	2	—	3	—	—	3
February	25	—	19	5	1	15	—	1	14
March	17	—	11	6	—	17	—	1	16
April	16	1	12	3	—	20	—	4	16
May	16	—	12	4	—	13	2	9	2
June	36	10	18	3	5	12	—	10	2
July	34	15	11	5	3	37	34	3	—
August	22	9	11	1	1	28	26	2	—
September	26	14	9	3	—	18	18	—	—
October	18	13	3	2	—	11	10	1	—
November	21	11	5	4	1	14	12	2	—
December	—	—	—	—	—	—	—	—	—
Total	242	73	120	38	11	188	102	33	53

Parasites

Table 2 shows the overall incidences and intensities of *Crepidostomum metoecus, Cystidicola farionis, Rhabdochona* sp. and *Pomphorhynchus laevis,* the four major helminths parasitising salmon and trout.

In general, older fish were the more heavily parasitised. However, *P. laevis* infections in trout showed highest incidence in 0+ fish and highest intensity in 1+ fish and both indices decreased with increasing host age. The monthly variations in incidence and intensity of infections of all four parasites in trout and salmon during 1980 are shown in Figs. 1-4.

Other parasites occasionally encountered include *Crepidostomum farionis* (Müller, 1784), *Cucullanus truttae* (Fabricius, 1794) and *Capillaria* sp.

Table 2. The occurrence of parasites in different age groups of salmon and trout during 1980.

		TROUT					SALMON			
		All Ages (n = 242)	0+ (n = 73)	1+ (n = 120)	2+ (n = 38)	3+ (n = 11)	All Ages (n = 188)	0+ (n = 102)	1+ (n = 33)	2+ (n = 53)
C. metoecus	incidence (%)	17	7	22	24	18	0	0	0	0
	intensity	3.6	1.6	3.2	5.2	6.5	0	0	0	0
C. farionis	incidence (%)	17	1	21	32	18	9	1	3	28
	intensity	2.5	1.0	2.2	3.4	1.5	2.5	1.0	1.0	2.7
Rhabdochona sp.	incidence (%)	29	4	34	53	64	38	4	70	83
	intensity	7.4	1.0	4.6	9.4	20.1	9.5	1.7	5.1	12.6
P. laevis	incidence (%)	46	49	46	42	36	12	5	12	26
	intensity	2.4	1.8	3.0	2.4	1.2	2.7	1.6	1.5	3.4

Crepidostomum metoecus (Fig. 1)

C. metoecus was found in trout only. The incidence of infection appears to follow a definite seasonal cycle. From a peak of 48% in February, incidence declined gradually during the following months, to zero in July. In October and November incidence again increased indicating the onset of a new period of infection.

The intensity of infection was not severe. Values were higher in May and June than in previous months but the highest intensity (9.6) was observed in November, indicating a large input of parasites in the initial stages of the new cycle.

Cystidicola farionis (Fig. 2)

The pattern of incidence of infection was similar in both trout and salmon, with a maximum in winter/spring and a minimum in summer/autumn. Incidence was generally higher in trout than in salmon.

The intensity of infection in both hosts was low, never exceeding a mean parasite burden of four.

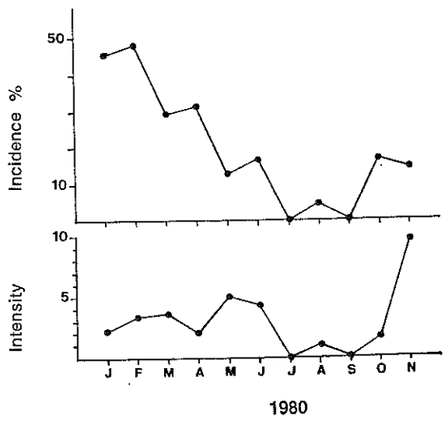

Figure 1. Monthly changes in incidence % (upper) and intensity (lower) of *C. metoecus* in trout in 1980.

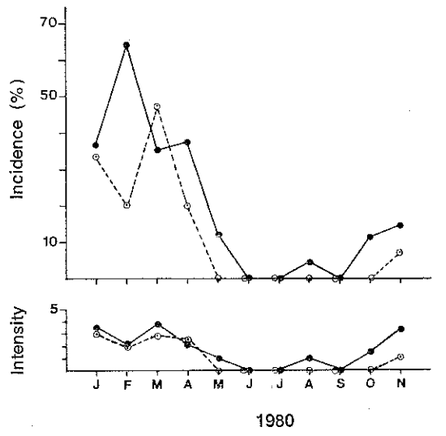

Figure 2. Monthly changes in incidence % (upper) and intensity (lower) of *C. farionis* in trout (full line) and salmon (dotted line) in 1980.

Rhabdochona sp. (Fig. 3)

The incidence of *Rhabdochona* sp. infections showed seasonal cycles in both salmon and trout. The peaks, however, occurred in spring/summer rather than in winter/spring, in contrast to those of *C. metoecus* and *C. farionis.* Infections of *Rhabdochona* sp. in salmon were heavier than those in trout and were established earlier in the year. In salmon, incidence reached 94% by March and remained around that level until June. In trout, during the same period, incidence gradually reached a maximum of only 81% (May).

The intensity of *Rhabdochona* sp. infections in salmon was relatively high during March, April and May while in trout comparable values were reached only in May and June.

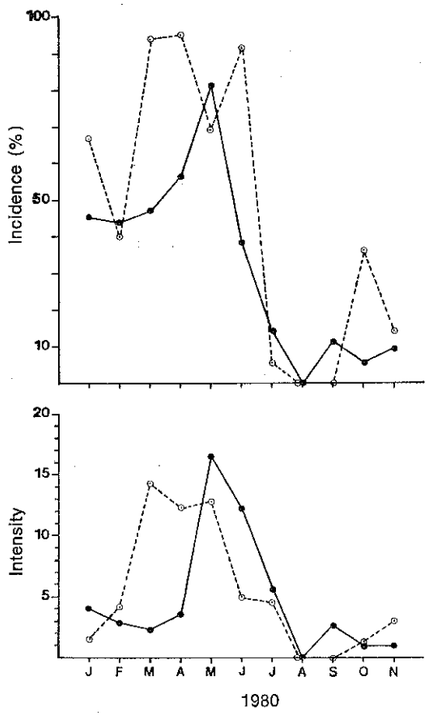

Figure 3. Monthly changes in incidence % (upper) and intensity (lower) of *Rhabdochona* sp. in trout (full line) and salmon (dotted line) in 1980.

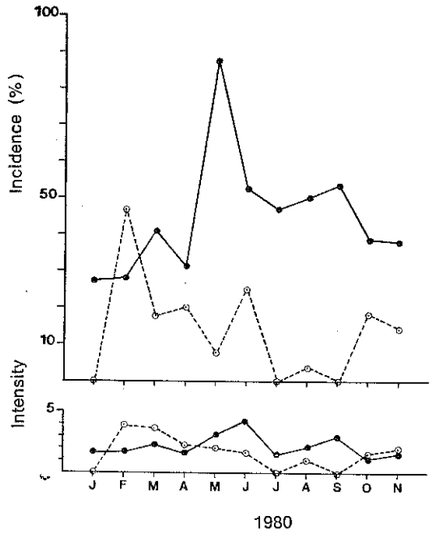

Figure 4. Monthly changes in incidence % (upper) and intensity (lower) of *P. laevis* in trout (full line) and salmon (dotted line) in 1980.

Pomphorhynchus laevis (Fig. 4)

The patterns of infection differed in trout and salmon.

Trout were found to be infected with *P. laevis* all year round. In trout the lowest incidence, 27%, was observed in January; it rose slightly from then until April, peaked sharply in May and dropped back to around 50% in June to September. Newly acquired *P. laevis* were unattached and free in the intestine whereas the established older forms were attached. The occurrence of unattached forms in trout samples varied by month: it was highest at 81% in May; the next highest was 30% in June, compared to between 0% and 20% in all other months. It would appear from observations on the incidence of *P. laevis* and also from the occurrence of unattached worms that the main influx of parasites took place in May and June, and that much smaller numbers of *P. laevis* were acquired by trout in other months.

The intensity of infection in trout did not exceed 5% during the year, but there was an increase in summer coinciding with the increase in incidence observed at that time.

The incidence of *P. laevis* in salmon fluctuated erratically and was generally lower than that in trout. The highest values of incidence and intensity of infection were found in spring samples, as 2+ salmon, which had much heavier infestations of *P. laevis* than either 0+ or 1+ age classes (see Table 2), occurred in the spring samples only (see Table 1).

Intermediate hosts

When the Ephemeroptera and Crustacea of the river benthos, taken in monthly samples, were examined, it was discovered that *Baetis rhodani* (Pictet) carried the larval stages of *Rhabdochona* sp. and *Gammarus duebeni* (Liljeborg) the larval stages of *P. laevis.*

The seasonal variations of *Baetis* spp. and *G. duebeni* in the benthos are given in Table 3. *B. rhodani* was the dominant baetid in the Shournagh, but many small nymphs of this genus taken in benthic samples could not be speciated, hence all baetids *(Baetis* spp.) were considered collectively in the results. *Baetis* spp. showed two peak periods of occurrence, March/April and August/September: this was largely attributable to the bivoltine nature of the most abundant species, *B. rhodani.*

Rhabdochona sp. larvae were found in the baetids of the overwinter generations only, up to June; but not in the summer generations emerging in August/September. Because of the limited numbers examined in some months (Table 3) further investigation is required to confirm this finding.

The numbers of *G. duebeni* in the benthos displayed no obvious seasonal variation, but % abundance was very low during March to June.

P. laevis cystacanths were found in *G. duebeni* samples in all months.

Table 3. The number and % abundance of *G. duebeni* and *Baetis* spp. in samples of the benthos during 1980.

	G. duebeni		*Baetis* spp.	
	Actual number	% Abundance	Actual number	% Abundance
JANUARY	86	12.6	36	5.3
FEBRUARY	32	10.6	18	5.7
MARCH	54	6.4	142	16.8
APRIL	56	6.6	98	11.6
MAY	106	4.9	31	1.4
JUNE	52	2.1	8	0.3
JULY	88	17.6	5	1.0
AUGUST	125	32.4	46	11.9
SEPTEMBER	104	33.1	23	7.3
OCTOBER	53	28.5	7	3.8
NOVEMBER	27	14.1	5	2.6

The % occurrence and % number of *G. duebeni* and *Baetis* spp. in the diets of salmon and trout, as indicated by analysis of stomach contents, are given in Table 4. Predation on *Baetis* spp. was greatest during the periods of greatest benthic availability: March/April and August/September. *Baetis* spp. was a more important food item in the diet of salmon than in the diet of trout, with 100% occurrence being recorded on several occasions, including March/April when *Rhabdochona* sp. larvae were present. It seems likely that the much heavier *Rhabdochona* sp. infections found in salmon may be largely due to this difference in the diets of salmon and trout.

G. duebeni was a major food item in the diet of trout but not of salmon (Table 4). The overall incidences of *P. laevis* infections in the hosts for the year would seem to reflect this difference in diets, with 46% of trout being infected but only 12% of salmon. However, the period of greatest acquisition of *P. laevis* by trout was May/June when both availability in the benthos of *G. duebeni,* and feeding by trout on it, were at their very lowest for the year. Therefore, highly selective feeding on infected *G. duebeni* must have taken place at that time.

Table 4. *G. duebeni* and *Baetis* spp. in the stomachs of trout and salmon during 1980.

			G. duebeni		*Baetis* spp.				*G. duebeni*		*Baetis* spp.	
	No. trout examined	No. trout with food	% occurrence	% number	% occurrence	% number	No. salmon examined	No. salmon with food	% occurrence	% number	% occurrence	% number
JAN.	11	11	55	13.1	45	9.5	3	—	—	—	—	—
FEB.	25	24	83	17.9	46	11.1	15	15	7	0.4	87	36.4
MAR.	17	17	65	14.5	88	23.6	17	17	12	1.2	100	22.6
APR.	16	16	37	6.7	75	26.3	20	20	0	0	100	33.7
MAY	16	16	25	0.9	50	2.8	13	12	0	0	33	2.1
JUNE	36	33	6	0.2	45	5.7	12	9	11	0.5	44	10.8
JULY	34	33	12	0.9	45	4.7	37	36	0	0	75	21.3
AUG.	22	22	41	19.2	50	11.8	28	28	0	0	100	70.8
SEPT.	26	26	12	1.9	62	18.3	18	18	0	0	89	50.6
OCT.	18	18	28	4.5	33	7.5	11	10	0	0	100	40.0
NOV.	21	19	68	46.1	11	2.6	14	13	15	6.2	38	21.9

Site selection by parasites

The preferred site of infection of *C. metoecus* was the host pyloric caecae; 89% of all individuals being found in that region of the alimentary tract. *C. farionis* showed an even greater affinity for a particular site, occurring exclusively in the host swimbladder. By contrast, *Rhabdochona* sp. had a non-selective distribution, being found in the pyloric caecae and throughout the intestine of both salmon and trout.

In the case of *P. laevis,* site selection in trout only is considered, since few worms were found in salmon. Table 5 shows the distribution of attached and unattached forms of the parasite in the alimentary tract of trout. Unattached *P. laevis* were found in all regions of the gut, but they showed a slight preference for the more posterior sites: sites 50-70% of the intestine. Attached *P. laevis* were much more confined in distribution, site 50-60% bearing the greatest burden of worms (53%). Separate analysis of the distribution of male and female attached *P. laevis* revealed that site selection was similar in both sexes.

Table 5. The distribution of *P. laevis* in the alimentary tract of trout.

P. laevis	SITE										
	Pyloric caecae	% distance along the intestine									
		0—	10—	20—	30—	40—	50—	60—	70—	80—	90—
unattached % (n = 108)	3.7	3.7	2.8	4.6	7.4	10.2	24.1	19.4	9.3	4.6	10.2
* attached % (n = 164)	—	—	—	—	0.6	15.2	53.0	18.9	9.1	1.2	1.8

* permanently attached to the intestinal wall by host encapsulation of the bulb and proboscis.

DISCUSSION

In considering the population biology of the parasites of freshwater fish Kennedy (1970, 1972a) described two types of parasite-definitive host system; one in which the parasites exhibit marked seasonal cycles of occurrence, and the other lacking marked seasonality. Three of the helminths studied in the Shournagh salmonids belong to the first grouping, *C. metoecus, C. farionis* and *Rhabdochona* sp. Recruitment of each of these three species is confined to a limited period of the year, due primarily to the seasonal availability of infective larvae in the diet, but possibly also to the influences of seasonal temperature fluctuations (Kennedy, 1970). Awachie (1968) found that at temperatures in excess of 10°C *C. metoecus* was unable to establish itself.

P. laevis, on the other hand, is an example of a non-seasonal system where cystacanths are available, and recruitment into the definitive hosts may occur, all year round. Kennedy (1972b) attributed this pattern of *P. laevis* infections to a balance between (a) increased host feeding and therefore increased parasite acquisition but with high parasite mortality during summer months, and (b) decreased feeding but greater parasite survival during winter.

P. laevis has been recorded from numerous host species in Britain (Kennedy, 1974; Hine and Kennedy, 1974a), but it appears to be very localized in distribution, "high densities" occurring only in the Thames, Severn, Avon and Stour rivers (Kennedy, Broughton and Hine, 1978). In the Avon, *P. laevis* used *Gammarus pulex* (L.) as its intermediate host, while the preferred definitive hosts were the barbel, *Barbus barbus* (L.), and the chub, *Leuciscus cephalus* (L.) (Hine and Kennedy, 1974a). In these fish hosts *P. laevis* showed maximal incidences and intensities and also the greatest occurrence of mature and gravid worms. Salmon and trout in the Avon were infected with *P. laevis* but only as second preferred hosts; incidences and intensities of infection were lower, and fewer worms became mature and gravid, than in the preferred definitive hosts (Hine and Kennedy, 1974a).

In Ireland, *P. laevis* is widespread in distribution, with very high incidences being recorded from salmon and trout (Kane, 1966; Pippy, 1969). Since chub and barbel are not found in Ireland Kennedy *et al.* (1978) suggested that there may be a special "strain" of *P. laevis* in Ireland. They proposed that in contrast with the situation in Britain this "strain" would use *Gammarus duebeni*, the common Irish freshwater gammarid, as an intermediate host and have salmonids as the preferred definitive hosts. As predicted, *G. duebeni* is found to act as the intermediate host of *P. laevis* in the Shournagh River, and the trout is the most heavily parasitized fish host. In further contrast with *P. laevis* infections in the Avon, the Shournagh *P. laevis* in trout showed an increase in incidence during the summer, albeit being "non-seasonal" in the sense that incidence never dropped below 27% during the year. Furthermore, the intensities of *P. laevis* infections were never as great as have been reported by Hine and Kennedy (1974a, 1974b) for the Avon fish hosts. Even the site selection of *P. laevis* in the alimentary tracts of trout from the Shournagh differed from that of the Avon. In Avon trout, under experimental conditions, *P. laevis* settled predominantly in the most anterior site, viz. site 0-10% (Kennedy, Broughton and Hine, 1976); in trout from the Shournagh the parasites settled in the more posterior sites, site 50-60% being the preferred site.

While there appear to be significant differences in the ecology of *P. laevis* found in Britain and that in Ireland, the ecology of *C. metoecus* in the two countries is remarkably similar. Numerous workers in Britain, including Thomas (1958), Awachie and Chubb (1964), Awachie (1968) and Bwathondi (1976) observed seasonal cycles in incidence and intensity of *C. metoecus* infections and a site preference for the pyloric caecae similar to those noted in this study.

Ephemeroptera have previously been found to act as the intermediate hosts of *Rhabdochona* spp. (Gustafson, 1939; Hoffman, 1970) and in this investigation it was found that *Baetis rhodani* carried the larval stages of the *Rhabdochona* sp. in question.

Diet is a major factor in determining the parasite fauna of fish. In the Shournagh, the highest incidences and intensities of *Rhabdochona* sp. infections were recorded in spring/summer, at which time infected intermediate hosts (*Baetis* spp./*B. rhodani)* were abundant in the benthos and also featured prominently in the diets of both salmon and trout. Therefore, *Rhabdochona* sp. infections may be directly related to the quantity of invertebrate host available and eaten. In sharp contrast, the highest incidences and intensities of *P. laevis* infections, in trout, were found in May/June, at which time *G. duebeni* was not abundant in the benthos and was virtually absent from the stomachs of trout. In the case of *P. laevis* in trout, therefore, highly selective feeding on infected gammarids must have occurred in May/June; Kennedy *et al.* (1978) have shown experimentally that fish will prey selectively on gammarids carrying the cystacanths of *P. laevis,* rather than on uninfected forms.

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Gobiesocidae occurring in the coastal waters of Connemara

by

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ABSTRACT

Four species of clingfish occur in the coastal waters of Connemara. *Lepadogaster candollei* Risso inhabits sublittoral rocky areas. It may live for five years, growing to 86 mm. It matures in its second year and spawns during the summer. Its diet consists mainly of small crustaceans. *Lepadogaster lepadogaster* Bonaterre is a littoral species and is apparently rare on the Connemara coast. *Diplecogaster bimaculata* Bonaterre occurs sublittorally on broken shell and lithothamnion. It may live for three years, growing to 35 mm. *Apletodon microcephalus* Brook is found on the lower shore, clinging to the fronds of *Laminaria* and *Cystoseira*. It grows to 35 mm but seems to live for one year only.

INTRODUCTION

Four species of clingfish occur in Irish inshore waters, the Connemara clingfish *Lepadogaster candollei* Risso, the shore clingfish *Lepadogaster lepadogaster* Bonaterre, the two-spotted clingfish *Diplecogaster bimaculata* Bonaterre and the small-headed clingfish *Apletodon microcephalus* Brook. This paper presents information on their biology, based on specimens recorded from the Connemara coast in recent years.

LEPADOGASTER CANDOLLEI

The Connemara clingfish ranges from the British Isles to the Salvage Islands and extends through the Mediterranean Sea to the Black Sea (Briggs 1973). In Irish waters it is locally common on the west coast (Dunne and Konnecker 1976) and also occurs on the south coast (Wilson 1976, Minchin *pers. comm).* Within its range it is moderately rare (Briggs 1973). Because of its scarcity, little information has been published on its biology. Over fifty specimens have been captured on the Connemara coast in recent years.

Habitat

This clingfish occupies a range of habitats. It is sometimes taken on the lower shore among laminaria but it is most frequent sublittorally in sheltered rocky areas. It is often accompanied by other sublittoral fish notably the black goby *Gobius niger* L., the leopard-spotted goby *Thorogobius ephippiatus* Lowe and the Tompot *Blennius gattorugine* Brunnich. In the southern part of its range it may extend higher up the shore; Gibson (1968) recorded it in boulder-filled pools high up the shore at Banyuls-sur-mer.

Age and growth

The sagittal otoliths exhibit alternating opaque and transparent zones which are assumed to be formed annually. It was possible to estimate the age of 18 fish without difficulty; other specimens had been preserved in formalin and their otoliths were therefore useless for age determination. The smallest specimen recorded was a male measuring 21mm, captured at the end of May 1974. It was probably spawned the previous summer and was therefore almost one year old at time of capture. Fish of the same year class measured 21-28 mm. In the next year the fish may double its length; specimens aged 2+ taken in late May were 43-55 mm. Three year old fish measured 71-79 mm. The largest specimen recorded measured 86 mm (71 mm standard length) and was aged 5+. Briggs (1955) gives maximum size of 75 mm standard length. In both sexes, total length = standard length × 1.2.

Reproduction

Males are easily distinguished from females by their larger urinogenital papilla. The gonads of the fish taken in March were maturing while those recorded in late May were almost ripe. Spawning probably occurs from June onwards, which concurs with Fives (1970) who estimated the spawning season to extend from May to early July. All the one year old fish were immature, while the two year

old specimens taken in late May were ripening. It seems therefore that *L. candollei* becomes sexually mature in its second summer when it measures about 45 mm. The ovaries contained oocytes in various stages of development; it seems that these clingfish are partial spawners as are other species with a more southern distribution. The sample was too small to make a detailed estimate of fecundity; the number of ripening oocytes in three specimens measuring 64 mm, 55 mm and 50 mm were estimated 360, 212 and 148 respectively. As in other species fecundity increases with the size of the fish.

Diet

The percentage occurrence of the main food items is given in Table 1. A variety of food is consumed, the commonest items being copepods, isopods, amphipods and gastropods. Its diet on the Connemara coast is similar to its diet at Banyuls-sur-mer (Gibson 1968) except that amphipods are abundantly eaten at Banyuls and are less important at Connemara. This difference may have been influenced by the capture of the specimens at different levels below high water.

Meristics

Table 1 gives the fin ray counts and vertebral numbers and compares them with those of other authors. Numbers are generally in agreement, though the mean number of pectoral fin rays is lower than found by Briggs (1955).

Table 1. The percentage occurrence of the main food items of *Lepadogaster candollei* and *Apletodon microcephalus.* Data for Banyuls-sur-mer from Gibson (1968); data for Brittany from Gibson (1972).

	L. candollei		*A. microcephalus*	
	Connemara	Banyuls-sur-mer	Connemara	Brittany
Foraminifera	0	3	4	0
Polychaeta	10.5	14	8	0
Gastropoda	37	7	0	0
Bivalvia	10.5	34	0	0
Acarina	5	3	0	0
Ostracoda	21	14	12	50
Copepoda	37	38	92	100
Mysidacea	0	3	0	0
Isopoda	26	27	16	0
Amphipoda	17.5	93	36	100
Decapoda	17	3	0	0
Insecta (larvae)	0	0	4	0
Ophiuroidea	5	7	0	0
Echinoidea	10.5	20	0	0
Bryozoa	5	0	0	0
Pisces	5	0	0	0
Algae (fragments)	17.5	0	0	0
Number of fish	28	35	26	3
No. of empty stomachs	9	6	1	1

LEPADOGASTER LEPADOGASTER

The Cornish clingfish is sympatric with the Connemara clingfish, ranging from the British Isles south to Senegal and extending through the Mediterranean to the Black Sea (Briggs 1973). In Irish waters it is locally common. Wilson (1981) gives an account of its biology at Cape Clear Island (Co. Cork) while Dunne, Byrne and O Keefe (in press) give a systematic account of its biology at Kilmore Quay, Co. Wexford. This species is apparently rare on the Connemara coast. Three specimens measuring 21.5-43 mm were recorded by the author on Inishmore (Aran Islands) on 26/7/76.

APLETODON MICROCEPHALUS

The small-headed clingfish occurs in inshore waters of the north-east Atlantic from Argyll, Scotland to Messina, Sicily, but it is rare within this range (Briggs 1973). It is common in Irish waters (Went and Kennedy 1976) and is common at Connemara. Ryland (1969) records it at Mweenish (Carna) in the holdfasts of *Saccorhiza polyschides* (Lightf.) Batt. The present specimens were taken on the lower shore clinging to fronds of *Laminaria* and in clumps of *Cystoseira* sp. Le Danois (1913) also notes its occurrence in the holdfasts of *Saccorhiza* (as *Laminaria bulbosa)* at Roscoff.

Age and Growth

Twenty six specimens were recorded, 19 males (26-39mm) and 7 females (18-35mm). In most of these there were no 'growth' rings visible in the otoliths. One fish taken in late March was typical age-group 1+, the sagitta having an opaque centre, surrounded by a transparent zone with a narrow opaque periphery. Briggs (1955) gives the maximum size as 41.6 mm (standard length). It appears that at Carna *A. microcephalus* is predominantly an annual species.

Reproduction

Most of the fish examined were taken in February and March and had developing or ripening gonads. Specimens taken in September were spent. From this scant information it is evident that spawning occurs during the summer.

Diet

Table 1 gives the diet at Connemara and compares it with the diet at Brittany. The small-headed clingfish is a carnivore, preying on small crustaceans, particularly copepods, ostracods, isopods and amphipods.

Meristics

Table 2 gives some comparative meristic data. The mean number of vertebrae and fin rays are lower at Connemara. However, data from other areas are scarce and more examples from these areas need to be examined before any conclusions can be drawn.

DIPLECOGASTER BIMACULATA

The two-spotted clingfish ranges from Trondhejmsfiord, Norway to the Mediterranean and Adriatic Seas (Briggs 1973). It is common on the Connemara coast, where it occurs sublittorally on maerl.

Seven individuals were captured; four of these fish had growth bands (presumed to be annual) on the otolith and were aged as follows:

Total length	34 mm;	35.5 mm;	37 mm;	40.5 mm.
Estimated age	2+	2+	3+	3+

Fives (1970) suggests a spawning season extending from the end of May to late June or early July. This was confirmed by the condition of the present fish; the May and June fish were ripe, while the September specimen was spent.

The sample was too small to make a detailed analysis of its diet. Six of the fish contained food at the following frequencies:

Food item	Frequency	Food item	Frequency
Foraminifera	1	Mysidacea	1
Gastropoda	1	Isopoda	2
Acarina	1	Amphipoda	4
Copepoda	2	Decapoda	1

Like the other clingfishes, the two-spotted clingfish preys mainly on small crustaceans, the most frequent of which are amphipods.

Table 2 gives the fin ray and vertebral counts of 6 of the fish. Data are too scarce to draw any conclusions.

Table 2. Meristic counts of *L. candollei, A. microcephalus* and *D. bimaculata.* (R = range; $\overline{X}$ = mean).

	L. candollei		*A. microcephlus*		*D. bimaculata*	
DORSAL FIN RAYS	R	$\overline{X}$	R	$\overline{X}$	R	$\overline{X}$
Le Danois (1913)	—	—	5-7	—	5-6	—
Briggs (1955)	13-16	15	5-6	6	5-7	6
present specimens	14-17	14	4-7	6	4-7	6
ANAL FIN RAYS						
Le Danois (1913)	—	—	5-7	—	4-5	—
Briggs (1955)	9-11	10	5-7	6	4-6	5
present specimens	9-11	10	4-6	5	4-6	5
PECTORAL FIN RAYS						
Briggs (1955)	26-29	28	21-24	22	21-25	23
present specimens	25-28	26	21-23	22	23-25	24.5
VERTEBRAE (excluding urostyle)						
Fage (1935)	—	—	29-32	—	30-31	—
Briggs (1955)	—	—	29-32	—	30-32	
present specimens	29-31	30	28-31	30	29-31	30

SUMMARY

Four species of clingfish occur in Irish coastal waters, three of which are common on the Connemara coast. They are small benthic fishes which cling to the substratum by means of a sucker formed by modified pelvic fins. Their biology is similar in that they live for a few years (except *A. microcephalus),* spawn during the summer and feed upon small crustaceans. There is little or no competition between them for either space or food as they each occupy a different ecological niche.

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Population estimation of juvenile Salmonidae

by

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ABSTRACT

A small tributary of the River Boyne, the Castlekiernan River, was studied from 1973 to 1979. Estimates were made over this period of the survival of the important life stages of the trout population. The numbers per metre of river ova, fry and the three year classes present are given. Mean values of each of the life stages are used to produce a model of the population based on the Leslie matrix. The model is run over 10 generations using a Fortran IV computer programme and matrices and vectors that produce stable age distributions are compared. Some advantages of the matrix approach are discussed.

The ecological profile of both salmon and trout has greatly influenced the development of strategies for their management. The management of salmonid stocks has been based on the theory that maximum sustainable yields can be obtained by fixing escapement at some predetermined level. This level has been estimated by various means ranging from relatively sophisticated stock recruitment curves to arbitrary decisions based on the examination of the age structure of the population. In the case of the anadromous salmonids the upstream movement of the adult to the spawning areas and the downstream migration of the juvenile have provided opportunities for estimating numbers in the population and thus the production of stock recruitment curves. In the case of purely freshwater species such as brown trout *Salmo trutta* L. management has relied heavily on the interpretation of inventories. These inventories have included estimates of mortality, growth, numbers, recruitment and indices of water type, water quality, fauna and flora. The more extensive inventories have been used to estimate exploitable annual production. The aim however has always been to obtain maximum yield by regulating the numbers of spawning fish and this has been attempted in the main by restricting exploitation and/or imposing size limits.

The use and interpretation of inventories is detailed by Cuinat et al (1975), and the various means of appraising freshwater fisheries are outlined by Ricker (1968). The theory of stock and recruitment was outlined by Ricker (1954, 1958). Beverton and Holt (1957) derived recruitment curves similar to those suggested by Ricker. Central to a theory of stock recruitment is the concept that fish abundance at all life stages is maintained at a mean level by a combination of natural controls. The abundance will fluctuate around this mean value and the size of the oscillations will depend on the contributions of the various control parameters.

The use of stock recruitment curves has been limited because they require a long series of data, also it has proved difficult in many cases to establish a relationship between parent and progeny mainly because of difficulties in assessing the numbers of parents and progeny accurately. Inventories, while very useful, merely compare population numbers or estimates of production with figures for other areas and decisions on whether a particular stream is well stocked or not are based on these comparisons. They do not tend to provide a basis for management based on health and performance of a particular population.

The Leslie matrix method (Leslie 1945, 1948) offers a new approach to the study of salmonid populations and has some advantages over present models.

The basic Leslie system for describing complex populations sets out the numbers of the individuals in the different classes of the population as a column vector and pre-multiples these by a transition matrix. The model predicts the age structure of a population after a unit of time given both the

structure at the present time and a matrix whose elements represent age-specific fecundity and mortality. The discrete population theory enables the prediction of the population growth rate and the stable age distribution. The model in matrix notation can be written:

$$A\ at = at + 1$$

at = at, 0, at, 1, at, 2, ... at, n is a column vector representing the population's age structure at time *t* and *at, i* is the number of females alive in the age group *i* to *i + 1* at time *t*. *at + 1* is a column vector representing the age structure at time *t + 1*.

$$A = \begin{matrix} f_0 & f_1 & f_2 & \cdots & f_{k-1} & f_k \\ P_0 & 0 & 0 & \cdots & 0 & 0 \\ 0 & P_1 & 0 & & 0 & 0 \\ 0 & 0 & & & 0 & 0 \\ \vdots & \vdots & & & & \\ 0 & 0 & 0 & \cdots & P_{k-1} & 0 \end{matrix} \qquad \begin{matrix} N_0 \\ N_1 \\ N_2 \\ \vdots \\ N_k \end{matrix}$$

The f's representing the mean fertilities of the classes run across the top of the matrix and the P's representing the mean survival from one class to the next run down the sub-diagonal.

In matrix A then (f_x) equals the number of daughters born to females of age *x* in one unit of time, (P_x) equals the proportion of females at age *x* at time *t* that survive to time *t + 1* and *k* is the greatest age attainable. In this case the units of time are unequal and refer to stages rather than ages so that (f_x) equals the number of daughters born to females at stage (*x*) in any time interval. (Px) equals the proportion of females at age *x* in stage *t* that survive to stage *t + 1* and *k* is the last stage in the life history.

The column vector contains the number of individuals at each of k + 1 stages. For instance N_0 = the number of ova, N_1 = the number of 1 year olds etc. The vector is used to multiply across the transition matrix. This can be done over a number of generations representing the population at time *t* and time *t + 1*.

Usher (1971) shows that one of the latent roots of A (denoted by λ) has properties which ensure:

1 The Leslie Matrix model will always determine a meaningful age structure for the population.

2 The age structure will be unique, since whatever the size of the matrix being used there will be only one biologically meaningful solution.

In this work intrinsic rate of natural increase (r) defined by

$$d\ N/d\ t = rN$$

(N = size of the population at time *t*), is modelled using the Leslie Matrix approach. The mathematics are accomplished by means of a FORTRAN IV computer programme written by Dr. R. E. Blackith of Trinity College, Dublin.

The total population is obtained by adding the numbers of individuals in each stage at any one time, and the instantaneous rate of growth of the population is obtained by dividing the total population by the preceding total. The rate of growth per stage is the first latent root of the transition matrix. The natural logarithm of the rate of growth per generation is described as the intrinsic rate of natural increase.

The data used in this paper were obtained during work on the Castlekiernan River, a small tributary of the River Blackwater, which in turn is a major tributary of the River Boyne. The Castlekiernan

enters the River Blackwater near Carnaross. The Castlekiernan was chosen principally because it was of suitable size with regard to the fishing equipment available and relatively stable in terms of flow and depth.

Castlekiernan trout typically mature at 3 years and spawn in November (for the purpose of this work the fish were deemed to have their birthday on 1 November). The 0+ group fish do not put on sufficient growth to enable sampling with the electrofishing equipment until July of their 1st year so that there are no measurements of survival for 0 group fish from November to July.

The trout maintain territories and there is little movement of 0+ and 1+ fish in the tributary. An experiment with multiple marks including freeze branding verified this theory.

In April/May a high percentage of the 2+ year class migrate downstream. It was not possible, despite some tagging, to ascertain the extent in distance of this migration, but it is assumed that the trout moved to the River Blackwater or further to the main Boyne River. In November of each year there was an influx of 3 and 4 year old non-resident trout. These together with the small resident component formed the spawning stock.

The parameters required for a model of the trout population based on the Leslie Matrix in this tributary then are the survival of the various life stages and the associated fecundities. Details of the methods used to obtain these parameters are given by Browne (1980).

The mean number of ova per metre was estimated to be 26.6, the range being 18.6 to 34.6. By scale reading the average length for 3 year olds and 4 year olds was estimated at 23.2 and 26.6 cm respectively. The potential egg production was estimated as 500 and 1,000 respectively.

The populations of juvenile fish in the Castlekiernan was estimated on 16 occasions between 1974 and 1979. Because we were interested in the numbers of fish surviving in the same stretch of the tributary the results (such as the number of ova estimated) are expressed in numbers per metre of river rather than per square metre. This avoids the problem of varying widths of streams on different fishing occasions.

The numbers were estimated using a combination of the Petersen mark recapture and the two catch method of Seber and LeCren (1967). The results were occasionally checked by the successive fishing method. Fig. 1 shows all the data regressed against time. The time scale is in months starting with January of the year of first sampling as (0+) fish. Because the times of sampling are not always in the same month each year this graph is required to estimate mean annual survival. The survival from 1 year old to 2 year old and from 2 year old to 3 year old was estimated at 0.21. The numbers of 4 year olds in the population varied and was clearly low in some years. The mean survival of 3 year old to 4 year old was estimated to be 0.18.

It would be simpler from the point of view of the model to estimate the survival into a 3 years and over class. However, when the model was run with only one reproductive stage the population never reached a steady state. When there is only one reproductive stage pulses of individuals flow through the population without ever reaching a steady state. This has been shown by Bernadelli according to Blackith and Aldbrecht (1979).

The concept that a trout population must have a low intrinsic rate of natural increase is central to the use made of the matrix model in this paper. If the intrinsic rate of natural increase in the population is high the population would quickly reach extinction or overcrowding. The intrinsic rate of natural increase must fluctuate within strict limits around zero because of the regulatory mechanisms operating on a trout population. Using mean values for survival and fecundity the model should run in steady state, not increasing or decreasing. Various combinations of survival and fecundity were run and one or other parameter adjusted to have the model run in steady state.

The choice of vector is largely immaterial as the vector will tend towards stable values (if the model is run for long enough), depending on the choice of survivals and fecundities. In this case for convenience the numbers are for 100 metres of river:

1.

Ova	*Fry*	*1 Year*	*2 Years*	*3 Years*	*4 Years*
0	0	0	0	500	1000
0.07	0	0	0	0	0
0	0.77	0	0	0	0
0	0	0.21	0	0	0
0	0	0	0.21	0	0
0	0	0	0	0.18	0
2939	206	158	32	7	1

The model was run over a large number of generations until the intrinsic rate of natural increase was established. Matrix 1 shows the result was an intrinsic rate of natural increase of over 0.2. To arrive at a steady state the contribution of the 4 year old spawning group was reduced gradually. It proved impossible to achieve a steady state population. The best that could be achieved was an intrinsic rate of natural increase of 0.01 after 10 generations, with an ova contribution of 210. The contribution of ova from the 4 year group was having too small an effect on the population to allow it to reach steady state.

The information on the number of eggs per year class is probably more accurate than the estimate of the number of 3 year and 4 year olds contributing to the egg production. The vector which most closely resembles the population estimated is shown in (2). The contribution from the 3 year and 4 year old groups had to be reduced substantially to allow the model to achieve steady state. From this it would appear that the egg contribution probably from the 4 year olds is greatly overestimated. This may be due to the ratio of males to females not being 1/1 as assumed, or the number of fish being over-estimated.

2.

Ova	*Fry*	*1 Year*	*2 Years*	*3 Years*	*4 Years*
0	0	0	0	331	500
0.07	0	0	0	0	0
0	0.77	0	0	0	0
0	0	0.21	0	0	0
0	0	0	0.21	0	0
0	0	0	0	0.18	0
571	179	138	29	6	1

The key value missing is the number of ova per metre and until this value can be estimated with some degree of precision, the population cannot be more accurately described.

When the actual survival of autumn fry, September to November, is examined, the survival rate is lower than that suggested by the graph in Fig. 1. The model was rerun using a reduced survival for fry to 1 year old.

3.

Ova	*Fry*	*1 Year*	*2 Years*	*3 Years*	*4 Years*
0	0	0	0	400	470
0.07	0	0	0	0	0
0	0.67	0	0	0	0
0	0	0.21	0	0	0
0	0	0	0.21	0	0
0	0	0	0	0.18	0
2874	201	133	28	6	1

The model was run using matrix (3) and the 4 year old ova contribution was reduced until the model shown above reached a steady state. The model showed a contribution of 470 ova from the 4 year old group. The contribution of the 4 year old group is an area where no firm information is available. Whereas there are estimates of the numbers of 4 year olds available the proportion of male to female or the numbers fecund have not been satisfactorily established. The model may well represent the average population in the Castlekiernan.

The matrix was tested for sensitivity. The various parameters were increased in turn by 1%. The resultant intrinsic rate of natural increase was noted.

The most sensitive parameter was the survival from ova to fry, small changes in the survival at this stage can change the number of survivors dramatically. The number of 4 year olds surviving was not critical nor is the contribution of ova from this group provided the ova contribution from the 3 year olds remains high. The area where it is important to have good estimates on trout survival from the point of view of the Leslie matrix is at the ova to fry stage.

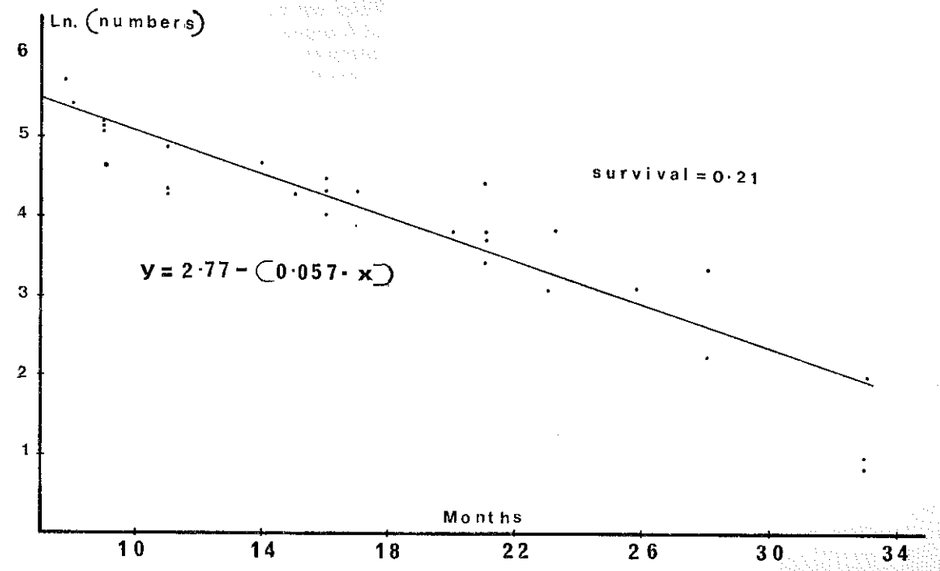

Figure 1. The natural logarithms of the numbers of trout surviving in 100 metres of the Castlekiernan River from 1973-1979 plotted against time using all the data available. The time scale is in months from January of the year of first sampling. An average annual survival figure is shown.

When the survival of ova to fry was reduced from 0.07 to 0.06 the model showed an increase in the intrinsic rate of natural increase, 0.15. The contribution of the 4 year old group was adjusted until the model ran in steady state. The resultant matrix is shown below (4) and comes near to the experimental values obtained for ova production by 3 year and 4 year old fish. The number of ova suggested is for 100 metres of river so that the ova laid down reach a value of 33 ova per metre which is in the higher end of the range estimated (18.6 to 34.6).

4.

Ova	*Fry*	*1 Year*	*2 Years*	*3 Years*	*4 Years*
0	0	0	0	400	915
0.06	0	0	0	0	0
0	0.67	0	0	0	0
0	0	0.21	0	0	0
0	0	0	0.21	0	0
0	0	0	0	0.18	0
3296	198	132	28	6	1

This matrix was considered to be the most likely representation of the trout population in the Castlekiernan river.

The matrix was again examined for sensitivity. The various parameters were increased by 1% in turn and the intrinsic rate of natural increase measured.

The most sensitive area was the survival from ova to fry. The change in the numbers of 4 year olds and the numbers of ova produced particularly by the 4 year old group was the least sensitive.

The vector which most closely fits the data is from matrix (4) and this is proposed as being the best representation of the trout population in the Castlekiernan.

DISCUSSION

From the data collected in work on the Castlekiernan River we can produce a number of models of the population. Of the four produced here, models 3 and 4 appear to describe the population best. The models show that the most sensitive areas of the life history are the ova to fry and fry to first year survival and that the area where more accurate data is required is on the relative contributions of 3 year old and 4 year old fish.

The main advantages of the Leslie matrix model are: *1* The matrix describes complex populations in simple terms and allows easy manipulation of data. *2* The matrix focuses attention on areas of the life history where more information is required. *3* It allows the manipulation of known values to give a range for doubtful values. *4* It provides a means of testing proposed experimental or management techniques or practices by predicting changes in specific parameters.

It was suggested that the Leslie model was unsuitable in this case because the time intervals between stages were not of identical length. When the model was run omitting the fry stage and adjusting the survivals accordingly to make time intervals identical, no material difference was obtained in the population vectors.

The assumptions underlying the model as used here do not explicitly take account of the regulatory mechanisms which control trout populations. These mechanisms could however be incorporated in the auxiliary matrix available in the programme. The Leslie model can still, however, only be viewed as a preliminary model which can serve as a useful tool in the investigation of trout populations.

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A technique for estimating brown trout *Salmo trutta* L. populations in Irish lakes

by

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ABSTRACT

A procedure for obtaining standing crop estimates of lake brown trout populations, using an introduced "marker group" of fish is described. Data illustrating the accuracy of the procedure are presented. The limitations of the technique are discussed.

INTRODUCTION

In 1975, a research programme was undertaken by the Inland Fisheries Trust Incorporated to obtain quantitative information on wild trout populations in Irish lake fisheries and to evaluate the effectiveness of trout stocking programmes.

Fishery development work in Irish waters indicated that the options, in terms of trout sampling techniques, were limited. The topography of Irish lakes, particularly their numerous exposed rocky shorelines and extensive *Chara* beds, meant that seine netting techniques were impractical. Fyke nets are inefficient as "trout traps" except in very shallow ponds. Wire traps, as described by Ricker (1942) and Worthington (1949), do not capture trout in Irish lakes in significant numbers. Trawling gear, which had been used successfully by Thorpe (1974) to obtain lake trout population estimates in Loch Leven was not available. Nylon gillnets were the only efficient means available for capturing trout in these waters.

Trout released from gillnets are often badly descaled and many individuals may not survive. Thus, a standard capture/recapture exercise could not be operated with this type of gear.

These difficulties lead to the testing of an unconventional mark-recapture system which had been used previously on salmonid populations by Hansen (1971) and Cragg-Hine (1975).

MATERIALS AND METHODS

Planted trout were used as a "marker group" in a mark-recapture type estimate procedure. The introduced fish were usually tagged with deflagged Floy anchor tags. They were scattered in small numbers over all areas of a lake. The fishery was netted subsequently with gangs of gillnets which were capable of catching a random cross section of a trout stock in the length frequency range 19.8 to 48.0 cm (O'Grady, 1981).

Gangs were fished either suspended from the surface or with the lead line lying on the lake bottom. These two specific areas in the vertical plane were selected for sampling because Kennedy and Fitzmaurice (1971) had indicated that brown trout in Irish lakes fed principally in these zones. Net sites were selected by a random sampling system formerly used by Cooper and Latta (1952). Areas less than the depth of the nets (two metres) were not sampled because the gangs would have been operating as tangle nets in such circumstances.

Net gangs were set each morning and lifted twenty four hours later. The estimate procedure was completed as quickly as possible, usually over a four day period because Miller (1951 and 1958) found that planted trout *(Salmo clarki* Richardson) often died a few weeks after stocking when introduced into a "competitive environment". This basic system was employed for each population estimate on all of the nine lakes in question. A minimum of thirty and a maximum of eighty random net gang samples were taken in the course of any estimate.

Up to 34,000 autumn yearling or two year old introduced marked trout were used to carry out an estimate. Large subsamples (500 fish) of the planted group were always measured prior to stocking to estimate the proportion of the stocking which were 19.8 cm or greater in length and thus would be retained, if captured, by the net gang.

Numbers of fish predators were small in all of the waters in question and so no allowance was made for the number of introduced trout which they ate prior to, or during, the course of an estimate. Angling crops were negligible while these estimates were in progress. Occasional trout caught in the nets were eaten by eels *Anguilla anguilla* L. and seagulls *(Larus* sp.). Such losses appeared to be random in relation to the catches and thus did not invalidate the estimates. The trout population estimate was calculated using Bailey's (1951) modification of the Petersen formula. The number of random sampling units taken in any estimate was thirty or greater. Thus, the central-limit theorem, as outlined by Elliot (1971) is applicable and 95% confidence intervals for an estimate could be expected to lie within 1.96 standard errors on each side of the estimate.

The Petersen estimator can be negatively biased unless:

$$m \times c > 4 \hat{N}$$

where m is the number of fish marked and released, c is the number of trout subsequently examined in the net sample and $\hat{N}$ is the Petersen estimate of the total number of trout (N) in the population. The values of (m x c) in all of the estimates in this study exceeded 4 $\hat{N}$, thus, bias can be assumed to be insignificant (Everhart et al., 1975).

Little quantitative data was available on Irish lake brown trout stocks when this study commenced. By relating the trout stock density figures recorded for Loch Leven (Thorpe, 1974) to the waters in question, initial values of m and c were obtained which might allow one to obtain an estimate with a standard error in the region of ten percent. The graphs designed by Robson and Regier (1964) were also utilised for this purpose. As the study progressed and a more accurate picture of population densities was obtained, values of m and c were adjusted, where possible, to suit the particular circumstances. When substantial numbers of both wild and previously planted farm fish were present in a lake, a large sample (c) was taken to ensure that a reasonable number of both "sub-populations" would be obtained for analysis.

RESULTS

This population estimate procedure proved practical and reasonable standing crop values were obtained for a number of fisheries.

It has been stressed that the use of introduced fish as a marker group may invalidate a population estimate procedure because they may be more, or less, catchable than the resident population (Ricker, 1958; Hansen, 1971; Cross, 1972 and Cragg-Hine, 1975). Thus, the validity of this technique had to be established before it could be adopted as a standard procedure.

The following data illustrates the accuracy of the technique. 3,323 two year old trout were planted in Lough O'Flyn (130 ha; M 58 80) in April, 1976. A large proportion (56.5%) of this planting was cropped by anglers in 1976. These fish were subject to very little predation by pike *Esox lucius* L. and there was negligible emigration of these trout from the fishery. A "marker group" was introduced to Lough O'Flyn in October, 1976, and a population estimate was obtained for the survivors of the April, 1976 planting. This $\hat{N}$ value, in combination with the angling crop in 1976, closely approaches the stocking figure for the group and therefore illustrates the accuracy of the technique (Table 1). The opportunity to collect additional direct evidence on the accuracy of this technique did not arise because in many cases stocked fish failed to survive for any length of time, insufficient knowledge regarding the emigration of planted trout from a fishery was available and anglers failed to crop a significant proportion of particular stockings.

Table 1. Data illustrating the accuracy of the population estimate technique in Lough O'Flyn.

Number of trout	Stocking	Estimated angling crop in 1976	Estimated number in the lake (October 1976)
3,323	April 1976	1,876	1,100
95% confidence limits		2,137—1,740	1,262—694

Additional data indicates, in an indirect way, that the population estimates did not underestimate stocks. In situations where small standing crops of trout were recorded in a fishery and subsequent

angling pressure was heavy, the estimated angling crop never exceeded the relevant standing crop figure (Table 2).

Table 2. Data on the estimated numbers of trout of specific groups, available to and subsequently cropped by anglers in Lough O'Flyn. Confidence limits (95%) in parentheses.

Estimated number of trout present $\hat{N}$ (N)	Date	Estimated angling crop	Cropping period
274 (435— 95)	February 1977	40 (90— 1)	1977
542 (889—195)	February 1978	94 (147—36)	1978
760 (1,197—323)	February 1978	61 (120—24)	1978

DISCUSSION

The data suggest that accurate population estimates were obtained for lake brown trout populations. The problems which can arise with this technique were avoided because the netting procedure was carried out quickly. This ensured a random distribution of the marker group among resident stocks and also allowed one to assume negligible mortality and emigration among marker stocks during the sampling period.

There was an obvious danger that the gillnets might be more selective for some size-groups than others among the resident stock if different sections of the population had widely varying feeding habits while the test netting was in progress. Should this situation arise it would obviously invalidate the estimate.

The Irish lake brown trout dietary study of Kennedy and Fitzmaurice (1971) suggested that this would not be a problem. In the spring and autumn months, fish in the 20 cm to 50 cm length range tended to feed on a narrow range of invertebrate species and thus are likely to be foraging in a similar manner. All of these trout estimates were carried out in the spring or autumn months. An analysis of the stomach contents of trout captured during these surveys confirmed this point and thus suggested that fish in this size range were equally prone to capture by the nets. In addition, Flick and Webster (1962) have shown that wild and domestic stocks of brook trout *(Salvelinus fontinalis)* are equally prone to capture in gillnets.

This technique has its limitations. A relatively large planting of trout is required if one is to obtain a standing crop figure with a small standard error. Such stockings may be unnecessary in fishery management terms. Even if they are required, published data suggests that a staggered stocking programme, rather than a large single planting, may be more beneficial in terms of angling returns (Shetter and Hazzard, 1940; Needham, 1947; Mullan, 1956; Oliver, 1968; Brown, 1970; Fleming-Jones, 1974 and Crisp and Mann, 1977).

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Quantification of trout stocks in an alkaline river fishery

by

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ABSTRACT

Several tributaries of the River Shannon were developed as brown trout fisheries by the former Inland Fisheries Trust and this development work is being continued under the Central Fisheries Board which was established in October 1980. Stock assessments were confined to anglers' reports and visual sightings during predator control operations. In 1977 and 1978, standing crop estimates were carried out on the main trunk of the Little Brosna River. A length of approximately 30 km of the river was studied. The average width was about 10 m, having a mean depth of less than 1 m; however, depths exceeded 3m in several pools.

It is estimated that the entire length contained in excess of 27,000 trout > 7.0 cm. The river was studied in 9 sections in which densities varied greatly, with one trout every 4.3 to 34 m^2. Standing crop data for these sections indicate carrying capacities of 36 to 196 kg per hectare.

INTRODUCTION

The Inland Fisheries Trust began preliminary development work on the Little Brosna River in 1952. The Trust subsequently acquired a long lease of this brown trout *Salmo trutta* L. fishery in 1966.

Development work included predator control (removal of pike *Esox lucius* L. and perch *Perca fluviatilis* L., and stocking with trout. Qualitative information on the resident trout stock was compiled during electric fishing operations to remove pike and this was supplemented by angling reports. The present study was initiated, in 1976, to provide more precise information on the resident trout stocks in this important river fishery.

TOPOGRAPHY AND SOIL TYPE

The Little Brosna River rises on the acid brown earths and brown podzolic soils, on the northern slopes of the Devils Bit mountain. The river flows north-west through undulating lowland of Lower Carboniferous origin in counties Tipperary and Offaly, before discharging to the River Shannon at Meelick. The soils in this area are of the richer grey-brown podzolic series with some associated gleys, consequently the river is highly alkaline (> 6.0 mEq HCO_3^-/1) and very productive. Waters of lower alkalinity drain the peaty slopes of the Slieve Bloom mountains to form the Moneen, and Camcor tributaries (Figure 1)

MATERIALS AND METHODS

Following preliminary surveys on short sections at Perry's Mill, Brosna Bridge and Ballyeighan in 1976, it was decided to quantify the total trout stock in the fishery from Milltown Bridge to Sharavogue Bridge. It was estimated, from the 1976 data, that this entire stretch might contain approximately 10,000 trout. The data of Robson and Regier (1964) indicated that 3,000 marked trout would be sufficient to provide an accurate estimate of the resident stock.

The marker group utilised were introduced fish-farm trout. The dangers associated with utilising introduced fish, as marked individuals in an estimate of this nature, are referred to by Ricker (1958). However, it was decided that for the present study hatchery reared trout should not be any less suitable than resident stock. The latter would of necessity be displaced during re-distribution and would, therefore, be expected to behave differently from undisturbed individuals. Hatchery trout were considered to be no less susceptible to shocking (galvanotoxis) than resident fish. In addition they would provide valuable information on the survival of introduced hatchery reared trout in a fishery of this nature as well as providing additional returns to anglers in the short term.

Three thousand 2+ trout (19.5—35.0 cm) from the hatchery at Fanure were distributed along the study area (one fish every 4 m) on Monday, 9 May, 1977. The pick-up operation, using ripple pulsed D/C (rectified A/C petrol driven generator) was carried out from Tuesday, 10 to Friday, 13 May. While stop-nets were not used to isolate the study area, migration was minimal and removal of marked individuals by anglers before completion of the estimate was insignificant. The same techniques were employed for the remaining estimates, Sharavogue Bridge to New Bridge in May 1978, using stocked fish of 14.2—35.0 cm.

To facilitate the investigations the fishery was divided into a number of workable sections. All resident fish captured were measured and a random sample was weighed from each section.

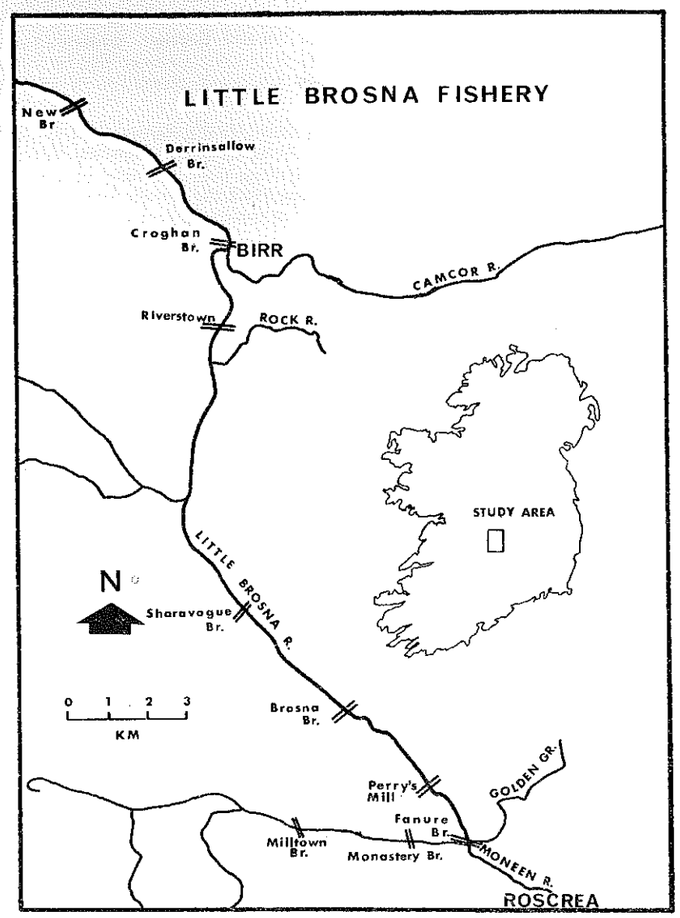

Figure 1. Map of the Little Brosna trout fishery from Milltown Bridge to the New Bridge. (Based on the Ordnance Survey by permission of the Government, Permit No. 1833).

RESULTS

Length distributions of resident trout in the fishery are presented in Figure 2. Only trout in excess of 7.0 cm (1+ and over) were captured. It is possible that more 1+ occur in the fishery than is evident from the results, this group possibly being underestimated due to size selectivity of the sampling apparatus (Cooper, 1952). Because of similarities in the population structure, length frequency data from Milltown Bridge to Brosna Bridge have been combined to provide a single distribution. The data for Riverstown to the New Bridge have been treated similarly. Larger fish constitute a greater percentage of the resident stocks in the remaining sections.

There is a particularly good length/weight correlation in all sections ($.884 \leqslant r \leqslant .98$), and trout attain 0.45 kg at about 33.0 cm. Fish of this size were most plentiful in the Sharavogue to Rock River area where some trout of about 1.5 kg (3.25 lb.) were encountered.

The details of the standing crop estimates for each section and other relevant data are presented in Table 1. All sections are demarcated by road bridges and the sections varied in length from 1,600 to 7,548 m. Upstream of Brosna Bridge the average depth in midstream is about 0.6 m. Downstream of this point the mid channel averages about 1.5 m with some pools to 3.5 m. Stream width was only determined for Sections 1—6; downstream of Riverstown the average width is about 14 m. Bank cover is extensive in Sections 7 and 8 with good cover also in Sections 3 and 9.

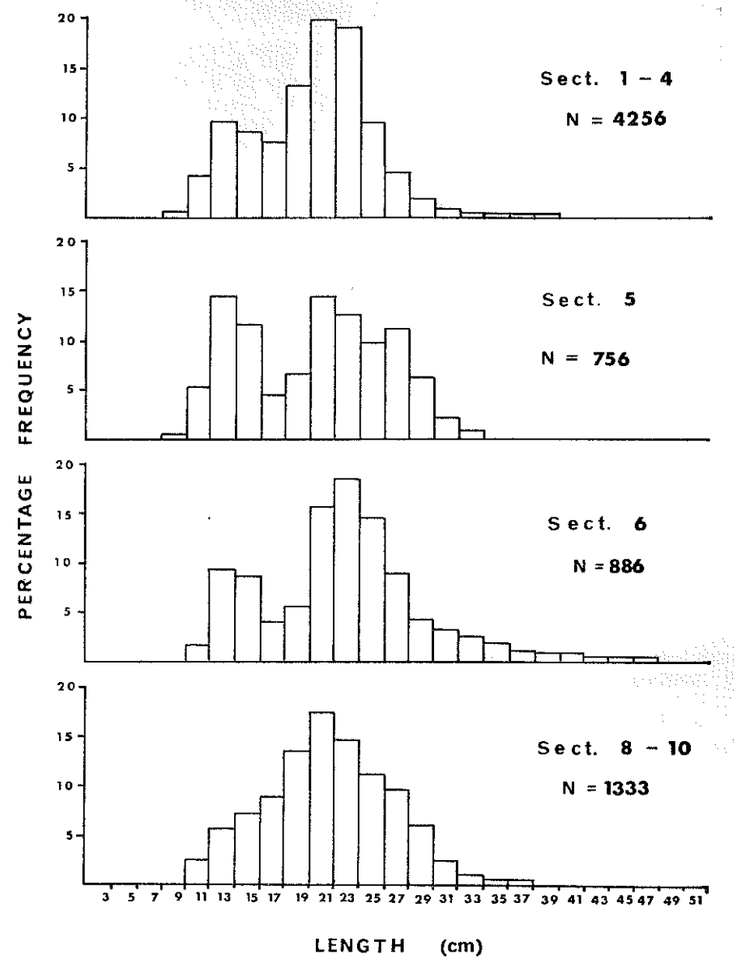

Figure 2. Length frequency distributions of brown trout in the Little Brosna fishery 1977-1978.

Trout are very abundant between the Rock River and Riverstown (1,000 m); this stock was not quantified but probably exceeds 1,000 trout. Including this section, therefore, about 30 km of river channel was examined and this was found to contain an estimated 27,000 resident trout. Considerable numbers of salmon parr were also encountered, particularly at Sections 3 and 7, these have been omitted from the estimates.

A total of 7,269 resident trout were examined during the present study. Trout $\geqslant$ 22.8 cm, (legal limit) formed quite a large percentage of the resident stock in several sections, most noticeably the Sharavogue to Rock River area. In this section 46.8% of the stock were $\geqslant$ 22.8 cm with a considerable number of trout over 33.0 cm. The latter weighed over .45 kg and several trout approaching 1.5 kg were encountered. This section was the longest single stretch examined (7,548 m). The water was deep and slow flowing and the trout were widely dispersed (1 per 34 m^2). Weed growth presents a problem in this area from mid-season onwards and access is limited. Consequently the section is not heavily fished.

Angling is confined to a very short portion of Section 7; fishing is not permitted in the Birr Demesne. Local regulations permit fly fishing only in Sections 2 and 5 and much of this water is best suited to dry fly fishing. These limitations and stream morphology may account for the high percentage of trout over the legal limit in these sections.

Fishing pressure is particularly heavy on Sections 3 and 4 (Fanure Bridge to Brosna Bridge) and 30-45% of the total annual catch is removed from this region in the first month of each season. Few fish over 22.8 cm were found in this area in May (Figure 2).

Some spawning is known to occur in Sections 1, 3 and 4, however predation is probably considerable on the young fry. Recruitment is provided mainly by yearlings (1+) from the headwaters and the tributary streams (Kennedy and Fitzmaurice, 1971). Recently, marked trout (12-14 cm) have been observed to enter the fishery in spring. This recruitment is also a contributory factor to the high percentage of small fish in Section 1 (from the headwaters) and Sections 3 and 4 (from the Moneen and Golden Grove tributaries).

Stock densities are greater in the shallower reaches towards the upper end of the fishery.

Table 1. Sections studied and the estimated resident stock in each area.

Location	Section Number	Area m^2	Estimated Resident Stock ($\hat{N}$)	95% Confidence Limits	Wild Fish in Sample ≥ 22.8 cms %	Area (m^2) Per Trout
Milltown Br.				2,458		
to	1	15,690	2,690	—	14.6	6.0
Monastery				2,788		
Monastery				1,791		
to	2	11,263	1,969	—	29.8	5.1
Fanure Br.				2,147		
Fanure Br.				3,028		
to	3	16,299	3,767	—	16.9	4.3
Perry's Mill				4,506		
Perry's Mill				2,990		
to	4	28,062	3,293	—	17.7	8.5
Brosna Br.				3,596		
Brosna Br.				3,191		
to	5	35,200	3,600	—	32.0	9.8
Sharavogue Br.				4,009		
Sharavogue Br.				2,551		
to	6	94,350	2,766	—	46.8	34.0
Rock River				2,981		
Riverstown Br.				2,205		
to	7	*37,632	2,482	—	37.8	15.2
Croghan Br.				2,759		
Croghan Br.				2,589		
to	8	*46,858	3,021	—	28.0	15.5
Derrinsallow Br.				3,453		
Derrinsallow Br.				1,524		
to	9	*33,796	1,836	—	21.0	18.4
New Bridge				2,148		

* Based on an approximate width of 14 metres.

DISCUSSION

Stream morphology and extensive bank cover interfered with the fishing operation in Sections 3, 8 and 9. Recaptures were low in these sections, standard errors of 10%, 7.3% and 8.7% respectively were obtained and this is reflected in the confidence limits for these zones.

Because hatchery reared fish were used in these studies individual estimates for each size grouping were not possible. While Le Cren (1969) suggests that there is little difference in susceptibility of different size groups to the electrofishing apparatus, other workers (Cooper, 1952; Lagler, 1978) state that this technique is size selective. Ricker (1958) refers to the work of Cooper and Lagler (1956), who found that the efficiency of an electric shocker varied from about 7% for 7.0 cm trout up to 40% for individuals of 28.0 cm; "even so, a Petersen estimate for the whole population was only 30% low".

The estimate of 27,000 trout in excess of 7.0 cm. must, therefore, be considered as a minimum figure because of a bias downwards due to the pooling of size groups.

McFadden and Cooper (1962) found that "the efficiency of the electro fishing gear generally increases as the fish became larger up to a length of about 7 inches" (18 cm) in streams similar to the Little Brosna. Consequently, Mense (1975) used only trout over 15.0 cm in length for his estimates. When the Little Brosna data are rearranged to incorporate only trout of this size, then the total estimated stock (sum of the sections) is 20,092.

Using the mean length of trout sampled in each section, an average weight was estimated from the length vs. weight relationship. The average weights so calculated are overestimated, however, this is in part counterbalanced by the weight of small trout not accounted for in the population estimates. The approximate total weight of the standing crop ranges from 34.6 kg per hectare in Section 6 (Sharavogue Bridge to the Rock River) to 196 kg per hectare at Section 3 (Fanure Bridge to Perry's Mill).

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Advances in the study of pelagic fish stocks in Ireland

by

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ABSTRACT

This paper describes the traditional methods used in the assessment of pelagic fish stocks in Ireland. These relied on the interpretation of changes in age distribution related to changes in catches and catches per effort to give an estimate of mortality and stock size.

Restrictions and closures enforced in many fisheries have necessitated the introduction of methods of stock assessments independent of the actual fisheries—such as egg and larval survey, and young herring survey. These methods, although recognized for many years, now play a much more important role in stock assessment. New methods (which may in future years replace the more traditional ones) such as hydroacoustic surveys, magnetic tagging, the use of biological tags and the studies of fish proteins are also discussed.

The purpose of all research carried out on fish stocks by the Fisheries Research Centre is simply to estimate the optimum catch that can be removed from a particular area or stock and subsequently to advise the fisheries managers—in the case of pelagic fisheries the managers being the Department of Fisheries and Forestry—on the best method to remove this catch.

The most important Irish pelagic fish stocks from a commercial point of view are mackerel *Scomber scombrus* L., herring *Clupea harengus* L. and sprat *Sprattus sprattus* (L.) and these species are the subject of assessment studies. Other pelagic species which are available in Irish waters in commercial quantities but which are not yet fished intensively are blue whiting *Micromesistius poutassou* (Risso) and horse mackerel *Trachurus trachurus* (L.).

The assessment of pelagic fish stocks depends mainly on the solution to two problems viz—1) the identification of the stock in question and the degree with which it mixes with other stocks and 2) the subsequent estimation of the abundance of the stock. G. P. Farran (1944) in the 1920s and 1930s, was perhaps the first person who studied Irish herring stocks. He produced substantial material dealing with age distribution, growth, meristic characters and fecundity data for herrings from various fisheries around our coasts. He is best remembered for work which he carried out on the differences in fecundity between autumn and winter spawning populations which enabled these populations to be distinguished clearly. However the investigations carried out by Farran and other earlier workers were not intended to provide information on stock abundances but rather on the identity of different stocks. This work therefore did not provide a basis for the regulation or management of fisheries in general.

After the retirement of Farran in 1946 research on pelagic fish stocks around Ireland ceased. It was not until the development of the herring fishery off the south coast in the late 1950s (now known as the Celtic Sea fishery) that the present research programmes were commenced. From that period all this research came under the umbrella of the International Council for the Exploration of the Sea (ICES).

Beginning in 1958 the first positive attempts were made to estimate the size of total stocks (Burd and Bracken, 1965) and to recommend the optimum sustainable yield. Because it was not possible to estimate directly the size of any stock it was necessary to use the actual catches, related to the required effort, (catch per unit of effort or c.p.e.) as an index of stock abundance. This index of abundance was combined with the age distributions and comparisons were then made from year to year to give a series of estimates of total mortality (z). Trends could then be detected in stock sizes by observing trends in total mortality and, if total catch were known, an estimate of the total stock could be made. It was however realized that this information was of limited value because, since no estimates were available about recruitment strength or variations in recruitment, it was not possible to forecast what the stock was likely to be. It was not possible therefore to make recommendations about optimum catches on a short term basis.

In the early 1970s a new mathematical method was introduced into fisheries research and was adopted by the various ICES assessment working groups. This method or variations of it, known as Cohort Analyses or Virtual Population Analyses, relied upon an accurate estimate of total mortality

from the most recent year of the fishery (usually derived from either catch per effort data or from tagging data) and an estimate of the total catch in that year, expressed as the numbers of fish landed for each age class. This information could then be used to back calculate both the total stock in numbers per age class (as far back as catches in numbers per age class were available) and also the fishing mortalities generated in each year. The method proved a very useful tool in that it gave valuable information on how a stock had reacted to fishing and also on how the recruitment of young fish had varied during the period under review. The total stock size, together with the recruitment level, could then be projected forward and its reaction to different fishing levels studied. This method now serves as a basis for estimating what catches should be allowed in various fisheries.

The following table gives an example of stock prognoses of the Celtic Sea herring stock, assuming different levels of recruitment and different total catches.

Prognosis of Celtic Sea Herring Stock

1979 Calculated Stock (tonnes)	Recruitment (millions)	Catch (t) 1979/80	Stock (t) 1980	Recruitment 1980	Catch 1980/81	Stock 1981
9500	100	4200	20400	30	0	25600
9500	100	4200	20400	30	4200	21600
9500	30	4200	10100	30	4200	10700

Most of the major Irish herring fisheries collapsed about 1976—the collapse in all cases being caused by a combination of a decline in recruitment and a mortality rate that was too high. This collapse could have been prevented if information on the decline in spawning had been available from either larval or young herring surveys. Such surveys had not, however, been initiated (Molloy, 1980a).

The collapse in major fisheries led to complete closures in the Celtic Sea, Donegal and Mourne herring fisheries and to the imposition of severe catch restrictions in other fisheries. The management of these fisheries therefore moved into a new era. The restrictions imposed—either on total catch per year or on catches per individual boats—meant that the traditional methods used for estimating stock sizes and total mortality, could now no longer be used. This has therefore led to a reappraisal of the methods used in estimating stock size and most of the present fisheries research is concentrated on improving these methods. The concepts, by which stock size is now estimated, are not new but the fact that they are vitally important means that they have had to be much better planned and organized than heretofore.

The main methods currently employed in the study of the abundance of pelagic fish stocks are:

Egg and Larval Surveys. Herring larval surveys, used to estimate the total production of larvae, in the Celtic Sea have been carried out each year since 1977. The results of these surveys will eventually be used (when a sufficiently long time series has been established) to forecast recruitment. At present the total production of larvae is used as an index of the size of the parent stock. (Grainger and Cullen, 1981). Similar surveys have been initiated off Donegal in the autumn of 1981. Egg and larval surveys have also been used to estimate the sprat population along the south coast (Grainger and Woodlock, 1981) and an egg survey, designed to estimate the abundance of the Western mackerel stock has also been carried out in 1980 along our southern and western coasts (Lockwood et al, 1981).

Young herring surveys. Surveys, carried out in the Irish Sea since 1979, have located the principal nursery areas for juvenile herring belonging to both the Manx and Mourne herring populations (Molloy, 1980b). These surveys will eventually forecast recruitment levels to the adult Irish Sea fisheries. Similar surveys were initiated in 1981 off the west and northwest coasts.

Hydro-acoustic surveys. Hydro-acoustic surveys employ the use of an echo integrator which gives a direct estimate of the number of fish or items detected per cubic metre of water. This type of survey, combined with a trawl survey, is now much used to get direct estimates of biomass. However there are still major problems to be solved in identifying the items observed and in calibrating target strength, before hydro-acoustic surveys can be successfully used for stock assessments. (Anon, 1981).

Airborne Remote Sensing Trials. The use of low light television in detecting shoals—based on the fact that shoals when moving through water disturb the plankton which then emit a phosphorescent glow—has been successfully used in pelagic fisheries in warmer waters (Hampton and Cram, 1973). This method gives a direct estimate of the number of shoals actually observed and provides information on the size and concentration of each shoal. Low light television trials were conducted with limited success in the Celtic Sea during December 1979.

Tagging. Tagging of herring and mackerel has provided information about migration and growth rate. In recent years large scale Norwegian mackerel tagging experiments have been conducted off the south-west coast (Hamre, 1970; Molloy and Kennedy, 1980). Magnetic tags are inserted into the body cavity of fish which subsequently are detected in fish meal factories in which they are removed from the meal by specially adapted magnets. However this method of tagging depends on large quantities of fish being reduced to fish meal and the present trend away from industrial fishing means that this method no longer gives meaningful results. A new system, involving magnetised stainless steel wire is now being developed and preliminary results are very encouraging (Corten, 1980). The wire can be colour coded so that release information on each fish is retained. This system relies on considerable portions of the catch being screened for tags—either at sea or when the catch is being unloaded ashore.

Parasites. In recent years different types of parasites specific to herring have been used by Scottish workers to separate herring originating from the North Sea and to the north west of Ireland. (MacKenzie, K. and Gallacher, J., 1981). Apart from differences that occur in species found in different areas, the degree of infestation of the host can be used to study the rate of mixture that occurs between different stocks.

Protein Studies. The extent of protein differences, which are unique to reproductively isolated populations, may also be used to permit distinction between juveniles of different stocks. (Anon, 1980). Electrophoretic trials carried out on herrings in the Irish Sea have shown that it is possible to separate Manx and Mourne spawning components. Iso-electric focusing, based on the accumulation of sample proteins in skeletal muscle has also been used to separate Manx and Mourne herring.

Although advances have been made in recent years in the study of pelagic fish stocks in Ireland, it is obvious that considerable problems still remain both in the study of the identity of fish populations and in the study of their abundance. The present restrictions imposed on fisheries have forced biologists to fall back on more or less traditional methods of assessments since no revolutionary new methods have yet been developed which give an accurate estimate of stock biomass. However because of the fact that fisheries research is now conducted on an international basis, through ICES, a tremendous pool of expertise is available and Ireland is well geared to avail of this expertise when necessary.

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Genetic variation in Irish brown trout populations: Identification and conservation of stocks

by

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ABSTRACT

Investigations have shown a high degree of genetic heterogeneity among brown trout populations. In at least one lake there is evidence for several genetically distinct and reproductively isolated sympatric populations. This diversity within the brown trout provides a resource of considerable importance for application in breeding and management programmes. In recent years, eutrophication, pollution, exploitation and unsound management practices have contributed to the loss of many natural brown trout populations. It is imperative that a detailed documentation of the genetic diversity of remaining pristine populations be undertaken in order that unique stocks be identified and appropriate conservation measures taken.

INTRODUCTION

Although the need for conservation of a diversity of species has long been recognised, it is only recently that attention has been given to the conservation of genetic diversity within and among populations of individual species. The maintenance of this genetic variability within species is vital for their long term welfare and, in the case of those harvested by man, for their rational management (Smith and Chesser, 1981). Before conservation measures can be implemented the distribution and extent of this genetic diversity must be identified.

A common feature of the brown trout, *Salmo trutta* L., and many other salmonid fishes, is the extreme variability and plasticity which they show in many aspects of their morphology, ecology and behaviour. For example, brown trout from different waters often vary in their body colouration, meristic features, growth rate and potential, age at maturity, food preferences, migratory behaviour, and time and place of spawning. Much of this variation is the result of environmental heterogeneity and estimation of the extent and distribution of genetic diversity cannot be based on such characteristics. Even when a phenotypic character is not environmentally influenced the interpretation of the genetic basis of its variation can be complicated by polygenic inheritance. Experiments on the heritability of growth rate and similar features do not provide information on individual genes and are therefore of limited value in the quantification of genetic variation within and among populations (Ryman and Ståhl, 1981).

Electrophoretic studies of enzymes and other proteins, i.e. the primary gene products, have enabled studies to be made of genetic variation within and among species, minimising environmental effects (Ferguson, 1980). Within the limitations of the technique, electrophoresis, accompanied by staining for specific enzymes and other proteins, allows determination of the genotypes of each individual at a selection of specific gene loci and provides useful markers for the investigation of the population genetics of fish (reviewed by Allendorf and Utter, 1979). In most cases for reliable results, a large number of loci and thus separate enzymes need to be examined.

MATERIALS AND METHODS

The information presented here has been obtained since 1976 in an ongoing series of investigations into the ecological genetics and systematics of the brown trout in Britain and Ireland. Details of the methodology, description and interpretation of results are given elsewhere (Taggart, Ferguson and Mason, 1981). To date 23 enzyme systems representing some 62 loci have been examined in over 50 natural populations and two hatchery stocks. Formal crosses have been carried out to verify the genetic interpretations of most of the polymorphic enzymes (Taggart, unpublished results).

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RESULTS AND DISCUSSION

Electrophoretic analysis of Irish brown trout populations have demonstrated their genetic complexity with large amounts of variation being found both within and among populations. Looking at the overall picture in Ireland as exemplified by the lactate dehydrogenase locus-5 (LDH-5) allelic frequency distribution, it can be seen that geographically close populations can be genetically quite distinct (Figure 1). The variation which exists in Irish brown trout can be summarised by calculating, on the basis of all loci examined, a coefficient of genetic identity (Nei, 1975) between all possible pairs of populations. The results of this are presented in the form of a dendrogram, produced by UPGMA cluster analysis, in Figure 2. Particularly apparent are the differences between the populations of the Lough Erne drainage system and those of north-eastern Ireland. The ferox type of Lough Melvin trout also appears in the Lough Erne group but its presence may be biased by its high LDH-5(105) allelic frequency, characteristic of the Erne populations. Under certain conditions the genetic identity coefficient can be used to estimate the time of divergence of populations (Nei, 1975). While the main branching point on Figure 2 can be seen to be at c. 90,000 years ago, the majority of the branching points lie within the past 20,000 years, suggesting that much of the genetic heterogeneity which is present to-day has arisen during the final fluctuating phase of the last glaciation or in post-glacial times. There are genetic differences between anadromous (sea-trout) and non-migratory populations of brown trout. Differences are most apparent in rivers such as the Glynn (Co. Antrim) where impassable waterfalls separate the two types, however in other drainages, (e.g. the Glenariff River, Co. Antrim), less pronounced differences occur in the absence of physical barriers to gene flow. Overall, the amount of divergence is low suggesting that both forms are of recent common origin. This is further shown by the failure of the migratory stocks to form a monophenetic group.

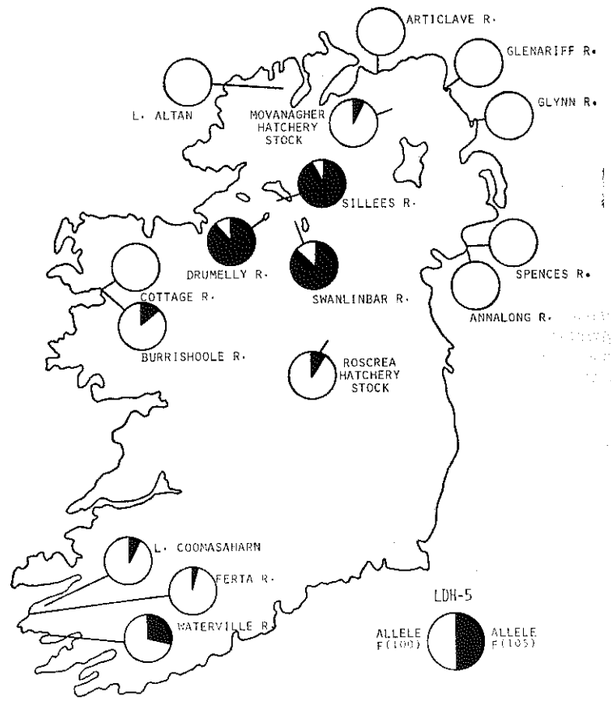

Figure 1. Geographical variation in allelic frequencies at the LDH-5 locus in Irish populations of brown trout.

Studies of anadromous populations provide additional evidence of the tendency of brown trout to form genetically distinct populations even when gene flow is not restricted by geographical features. Table 1 shows allelic frequencies for populations from four rivers between two and twenty miles apart on the County Down coast. It is apparent that there are significant allelic frequency differences among the populations. Most striking is the presence, at a substantial frequency, of the PGI-2 (65) allele in Spence's River trout, the only population studied to date which possesses this variant. The lack of this allele in adjacent populations and the variation in allelic frequencies at other loci, suggests

that gene flow is effectively absent. Much of this heterogeneity may be the result of the innate homing behaviour shown by many salmonid fishes, however factors such as effective population size and genetic drift may also be important.

Table 1. Allelic frequencies at four loci from four populations of brown trout in Co. Down

RIVER	N	Phosphoglucose Isomerase-2 (PGI-2) allele			Aspartate amino-transferase-1/2 (AAT-1/2) allele		Aspartate amino-transferase-4 (AAT-4) allele	
		100	135	65	100	140	100	74
Moneycarragh	61	0.99	0.01	0.00	0.93	0.07	0.97	0.03
Spence's	65	0.72	0.00	0.28	0.84	0.16	0.93	0.07
Annalong	34	0.94	0.06	0.00	0.59	0.41	1.00	0.00
White Water	40	1.00	0.00	0.00	0.89	0.11	0.80	0.20

Genetically distinct populations have been found even within a single water body. For example, Ferguson and Mason (1981) have described three reproductively isolated sympatric populations (known locally by the vernacular names of gillaroo, ferox, and sonaghen) in Lough Melvin. The application of Nei's value for time of divergence suggests that the populations have been isolated from between 90,000 (ferox/others) and 40,000 (gillaroo/sonaghen) years. Since these dates correspond to the early and middle stages of the last glaciation it would seem possible that these three types evolved in allopatric glacial refugia and independently colonised Melvin in post-glacial times, rather than by "sympatric speciation". They have presumably remained reproductively isolated by their distinctive reproductive behaviours and the ability of brown trout to home to their natal areas for breeding. Melvin is probably one of the last remaining examples of what may once have been a widespread situation of sympatric populations in Britain and Ireland. From a management point of view these populations must be treated as separate stocks, each with distinctive growth, ecological and behavioural characteristics.

The existence of genetic heterogeneity probably reflects adaptation to differing environmental conditions. This might explain why artificial stocking with a genetically different "generalised or mixed" strain of hatchery reared brown trout has not always been successful. For optimum stocking, therefore, separate stocks may need to be bred for use in different water bodies and for different angling requirements. Thus there is growing evidence that different strains of brown trout have different food preferences, growth rates and angling vulnerability. Stocking of several strains with different food and other requirements may result in a more efficient utilisation of the total environmental resources, leading to greater total yields than would be obtained through stocking a single strain. The existence of genetic variation between farm and natural stocks also provides intrinsically "tagged" fish for investigating the efficacy of such artificial stocking.

There is some evidence that the growth potential of brown trout is genetically determined. Thus there appears to be a correlation between the occurrence of the LDH-5(105) variant allele and the presence of large brown trout in that water system. As well as single locus effects the overall genetic variability (heterozygosity) of a population has been shown to be related to various fitness characteristics in many different organisms (Soulé, 1980). Farming practices can lead to a reduction in heterozygosity through inbreeding and genetic drift (Ryman and Ståhl, 1980). The heterozygosity of the small isolated population of brown trout above the waterfall in the Glynn river is lower (0.017 for 46 loci) than the larger anadromous population below the falls (0.045).

CONCLUSIONS

The genetic variation present in brown trout populations represents an important resource for management and selective breeding programmes as well as being essential for the future adaptation and survival of the species under changing environmental conditions. If this potential is to be realised suitable natural stocks must be available to act as source material. However, over recent years many natural populations of brown trout have been lost due to eutrophication, pollution, exploitation, introductions, hydroelectric power station construction, and unsound management procedures. Introduced hatchery-reared brown trout of mixed origin may form a bridge between natural populations resulting in the breakdown of reproductive isolating mechanisms and the possible loss of locally adapted stocks.

The increasing exploitation of water resources in Ireland means that it is imperative that potentially valuable stocks be identified and appropriate conservation measures taken. Electrophoretic

studies, coupled with ecological and behavioural investigations, provide the best hope of achieving this in the short time available for the pristine stocks which remain. In some cases it may be necessary to preserve unique and valuable gene pools, e.g. gillaroo, as separate hatchery stocks.

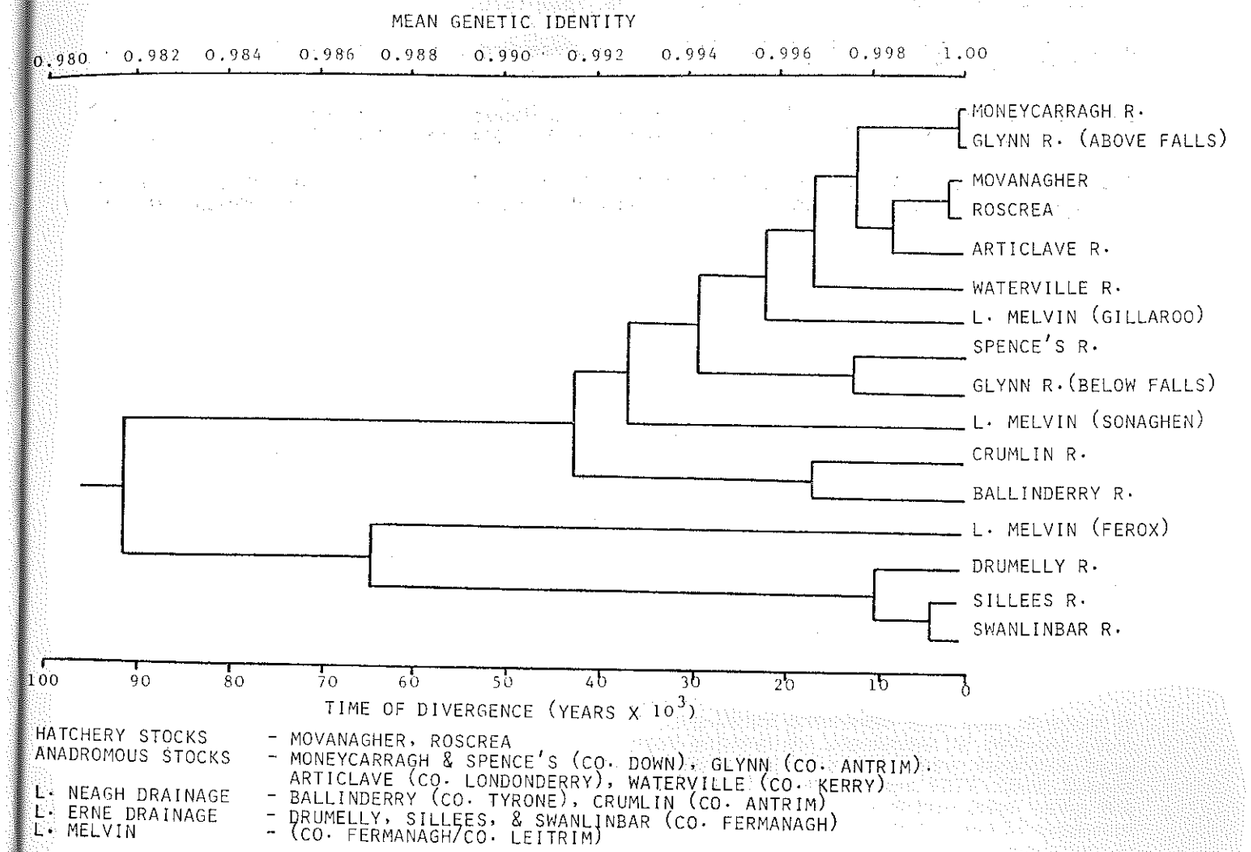

Figure 2. Dendrogram showing the genetic relationships and times of divergence of 16 populations of brown trout.

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The use of biochemical genetics to distinguish populations of Atlantic salmon, *Salmo salar*

by

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ABSTRACT

Atlantic salmon, *Salmo salar* L., from four Irish rivers were investigated at six polymorphic loci using starch gel electrophoresis. Significant differences occurred between rivers, whereas a sample of adults from one river mouth did not differ from juveniles. Genetics distances between rivers based on three loci were very similar, in contrast to earlier results involving another protein, which showed regional differences between salmon from western and southern Ireland. The results of this study imply that salmon from these rivers are genetically distinct and should be treated as separate stocks for management purposes.

INTRODUCTION

Most electrophoretically-distinct populations of marine fish species, such as the Atlantic cod, *Gadus morhua* L., occupy large areas of ocean (Sick, 1965 a and b; Jamieson, 1975; Cross and Payne, 1978). In contrast, populations of salmonid fishes have been found to be much more heterogeneous, with electrophoretically-distinct populations in most rivers and lakes (Allendorf *et al.*, 1976; Allendorf and Utter, 1979; Ferguson, 1980). The heterogeneity of the latter may be due to the accuracy of homing to natal spawning areas and to the glacial history of their habitats.

In the case of the Atlantic salmon, *Salmo salar* L., significant differences have been observed in the frequencies of alleles at the plasma transferrin locus between the populations of different rivers in North America (Møller, 1970; Payne, 1974). Two alleles segregate at the plasma transferrin locus in Atlantic salmon from Europe, but one is very rare (Payne, Child and Forrest, 1971; Child, Burnell and Wilkins, 1976). Thus, two races of salmon can be distinguished in the British Isles, using this locus, but populations of individual rivers cannot be differentiated. Wilkins (1972 a and b) suggested that other gene markers be sought. Cross and Ward (1980) showed eight enzyme loci, in addition to the previously discussed plasma transferrin locus, to be variable in one Irish sample. In this report, six of these enzyme loci are compared in samples of Atlantic salmon from four Irish rivers.

MATERIALS AND METHODS

Samples of parr were collected by electrofishing during the summers of 1977, 1978 and 1979. Figure 1 shows the rivers from which parr samples were taken. The adult sample was caught by commercial nets in the estuary of the River Blackwater in summer 1975. Samples of white muscle and liver were removed from the adults prior to storage whereas parr were frozen whole. Samples were stored at −25°C until required. Most electrophoretic determination took place within six months of capture although it was found that these enzymes were stable and could be typed for up to two years. Tissues for electrophoresis were either soaked overnight at 4°C in an equal volume of 2% phenoxyethanol in 0.1M Tris HCl buffer, pH 7.5 or homogenised in an equal volume of the cold buffer. Both methods gave satisfactory results, although the former method was better for extracting sorbitol dehydrogenase. Details of electrophoretic methods and enzyme staining are given in Cross and Ward (1980).

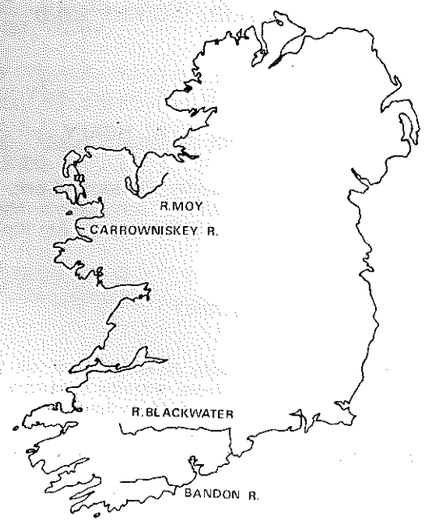

Figure 1. Outline map of Ireland showing position of rivers from which samples were obtained.

RESULTS

The frequencies of alleles at the six loci investigated are given in Table 1. No significant deviations from the expectations of the Hardy-Weinberg equilibrium were observed. Pairwise comparison of all samples for each locus yielded significant differences at two loci only (Table 2). No other comparisons were significant. It can be seen from Table 2 that no significant differences occurred between the adults taken in the estuary of the R. Blackwater and the parr sample from that river. In contrast, all four parr samples differed significantly at one or both loci.

Mean genetic identity and distance (Nei, 1972) was calculated for the four parr samples at dh^{-3}, Aat_s^{-2} and Me_m^{-2} (Table 3) and a UPGMA phenogram was produced (Sneath and Sokal, 1973) based on these genetic distances (Figure 2). It is recognised that a phenogram based on three loci only cannot be compared with results for other species in which a large number of loci were used. However, combination of the three loci, which show maximum heterogeneity between samples, allow the probable relationships between the four samples to be visualized.

DISCUSSION

We have demonstrated significant allele frequency differences between the Atlantic salmon populations of four Irish rivers, as have been shown for eastern North American rivers using the plasma transferrin locus (Møller, 1970; Payne, 1974) and for rivers in Sweden using the same enzyme markers as in the present study (Stahl, 1981). Khanna *et al.* (1975 a and b) had earlier found gene frequency differences between three Swedish populations of Atlantic salmon but these populations were hatchery-reared. It has been shown for brown trout, *Salmo trutta* (Ryman and Stahl, 1980) and cutthroat trout, *Salmo clarkii* (Allendorf and Phelps, 1980) that hatchery practice can alter gene frequencies.

No intra-river variations, as demonstrated by Stahl (1981) in one Swedish population, were detected in the present study, although it is recognised that the criterion of lack of statistical deviation from Hardy-Weinberg expectations has been shown to be insensitive (Fairbairn and Roff, 1980). Adult salmon taken from the river Blackwater estuary in 1975 had almost identical allele frequencies at Idh^{-3} and Aat_s^{-2} to a parr sample taken in that river in 1977, implying that gene frequencies are relatively constant over time. Stability of gene frequencies in time has been demonstrated previously in the genus *Oncorhynchus* (Utter *et al.* 1980).

Consideration of the phenogram (Figure 2) shows that enzyme markers neither confirm nor negate the theory, based on plasma transferin allele frequencies (Payne *et al.*, 1971) of two races of salmon in Ireland. Note that the transferrin locus was regarded by Sarich (1977) as being faster evolving than structural enzyme loci. In Figure 2, pairs of western and southern populations are shown to be more similar to each other, rather than clustering on a geographic basis. The lack of any apparent correlation between the clusters observed in the phenogram and environmental variables points to the initial difference between populations, being established by random processing coupled with small population sizes, and maintained by accurate homing.

Whether the observed differences are due to selection or stochastic processes cannot be resolved by our data. However, differences do occur and these rivers at least, (and possibly all Atlantic salmon rivers) should be regarded as having separate populations for management purposes.

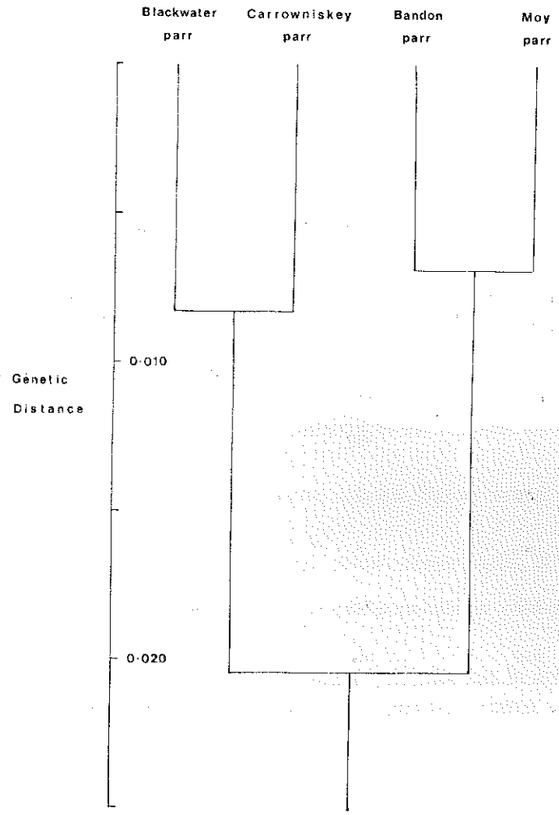

Figure 2. Phenogram based on genetic distance.

ACKNOWLEDGEMENTS

We thank Miss E. Twomey, M.Sc., B. Doolan and R. Fluskey, for providing the specimens, Prof. F. J. O'Rourke for laboratory space, R. McNamara and M. Timmons for technical assistance, Carbery Milk Products for financial asistance and Dr. D. J. Piggins for helpful discussion.

Table 1. Allele frequencies and sample numbers.

Locus	Allele	Sample: Blackwater parr[1]	Blackwater adults[2]	Bandon parr	Carrowniskey parr	Moy parr
Idh—^{3}	116	0.168	0.180	0.285	—	0.165
	100	0.832	0.820	0.714	1.000	0.835
	n	119	100	98	56	76
Aat_{s}^{-2}	100	0.672	0.683	0.781	0.723	0.835
	74	0.328	0.317	0.219	0.277	0.165
	n	119	93	96	56	88
Me_{m}^{-2}	115	0.453		0.540	0.472	0.521
	100	0.544		0.460	0.573	0.479
	n	118		112	55	96
Mdh_{s}^{-3}	100	0.986			1.000	0.993
	87	0.014			—	0.007
	n	111			56	72
Sdh—^{1}	100	0.582				0.564
	–72	0.418				0.436
	n	73				70
Sdh—^{2}	100	0.952				0.925
	28	0.148				0.075
	n	73				47

[1] Data from Cross and Ward, 1980; [2] data for *Idh*—^{3} from Cross and Payne, 1977.

Table 2. Comparison of samples based on X^2 test, with Yates's correction for *Idh*—^{3} allele frequencies above the diagonal and Aat_{s}^{-2} allele frequencies below the diagonal.

	Blackwater parr	Blackwater adults	Bandon parr	Carrowniskey parr	Moy parr
Blackwater parr	—	NS	**	***	NS
Blackwater adults	NS	—	*	***	NS
Bandon parr	*	*	—	***	*
Carrowniskey parr	NS	NS	NS	—	***
Moy parr	***	**	NS	*	—

NS = non significant; * = 0.050> P>0.010; ** = 0.010> P>0.001; *** = P<0.001.

Table 3. Mean genetic identity ($\overline{I}$) above the diagonal, and genetic distances ($\overline{D}$) below the diagonal, based on allele frequencies at *Idh*—^{3}, Aat_{s}^{-2} and Mdh_{s}^{-3}.

	Blackwater parr	Bandon parr	Carrowniskey parr	Moy parr
Blackwater parr	—	0.9840	0.9917	0.9858
Bandon parr	0.0161	—	0.9664	0.9331
Carrowniskey parr	0.0083	0.0341	—	0.9830
Moy parr	0.0143	0.0067	0.0172	—

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Haemoglobin and the salmon-grilse problem

by

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ABSTRACT

The complex haemoglobin patterns observed in Atlantic salmon occur in all populations. The rate at which the pattern undergoes ontogenetic development differs, however, between grilse and potential 2-sea winter fish in the wild. In this paper results are presented of an analysis of haemoglobin patterns of grilse-type and potential 2 sea-winter type fish of a single population grown in sea cages. The data confirm that haemoglobin development is more rapid in grilse, and the implications of this observation are discussed.

INTRODUCTION

The Atlantic salmon "grilse" is a true biological enigma. It returns to fresh-water to spawn having spent only one winter in the sea, but it may return again to spawn subsequently as a two, or more, sea-winter salmon. It does not breed true, although the proportion of offspring of grilse x grilse matings which return as 2 sea-winter fish is small. The relative contributions of genotype and environment to the grilse phenotype are unknown and a matter of some dispute (see review by Gardner, 1976). Neither are the nature and timing of the commitment to grilse phenotype clearly understood i.e. what factors, acting at what (critical?) time determine which individuals of a single cohort will return as grilse and which as 2 sea-winter fish?

The haemoglobin phenotype of the Atlantic salmon is equally complex. The number, intensity and relative mobility of the individual haemoglobins observed on electrophoresis alter regularly with increasing length of the fish, up to a maximum of nine anodal, and seven cathodal, components. Notwithstanding this complexity, the patterns observed in salmon of different populations throughout the northern hemisphere are remarkably similar, and no pattern has been observed to characterise any one population exclusively. (Westman 1970; Wilkins 1970). However, the rate at which the pattern alters ontogenetically in different populations may be different: grilse in Scotland, for example, have been shown to express a more advanced haemoglobin phenotype than salmon of the same size range collected at West Greenland (Wilkins 1968). This result suggests that at the end of their first sea-winter, grilse salmon and potential 2 sea-winter salmon differ in the rate and extent of their haemoglobin development as well as in the timing of their first sexual maturation: grilse exhibit an accelerated haemoglobin development and an accelerated first cycle of sexual maturation relative to these features in non-grilse salmon. In this paper the difference observed in the development of the haemoglobin pattern between grilse and non-grilse salmon is investigated at the level of the constituent globin polypeptides. It is, furthermore, shown to occur in fish of a single year-class reared together until the end of their first year of sea-life.

MATERIALS AND METHODS

Two separate samples of fish were investigated. The first consisted of those salmon and grilse collected in Canada, West Greenland and Scotland and analysed previously (Wilkins, 1968). These fish were collected from estuarine and coastal fisheries, and represent free-range fish characteristic of the commercial fisheries from which they were taken. The second sample consisted of sixty eight hatchery-reared salmon grown in a sea-cage at Lettermullan, Co. Galway and collected in August 1980 at the end of the first year of their sea life. These fish were members of a single year-class produced and reared together at Carrigadrohid Hatchery, Co. Cork and subsequently moved to the sea-cage in May, 1979. By the date of collection two morphological phenotypes were obvious within the population of a single cage. The phenotype identified by external appearance as "grilse" was characterised by a dark colouration, deep belly and generally more flaccid body condition. The "non-grilse" phenotype was characterised by silver colouration and leaner, more streamlined body shape. Separation of the sample into "grilse" ($n = 35$) and "non-grilse" ($n = 33$) was easily made by comercially experienced personnel prior to, and independently of, the analysis of the haemoglobin.

Electrophoretic patterns of the anodal haemoglobins were analysed and quantified as previously described (Wilkins 1968). The gels were stained with Amido Black 10B and the relative intensity of each stained haemoglobin band was assessed. Each anodal haemoglobin is a tetramer composed of one, or both, of two polypeptides labelled R and S together with one, or both of two other polypeptides labelled T and V (Wilkins 1970). Only one anodal haemoglobin, Hb A_4 (structure $R_2 V_2$), is observed in very small salmon. As the fish grows in length further anodal haemoglobins e.g. Hb A_5 (structure S_2 TV) become evident. Up to 9 anodal haemoglobins may be present in any individual (Wilkins 1968). Knowing the number and relative intensity of each haemoglobin, and its polypeptide structure, it is possible to estimate the relative proportions of the polypeptides R, S, T and V in each individual fish. These are expressed as the ratios $\frac{R}{R+S}$% and $\frac{V}{V+T}$%. These ratios were plotted against length for individual fish (sample 2) or against mean length of fish in different size categories (sample 1). Linear regression coefficients were calculated and statistical levels of significance were determined by Student's *t* statistic.

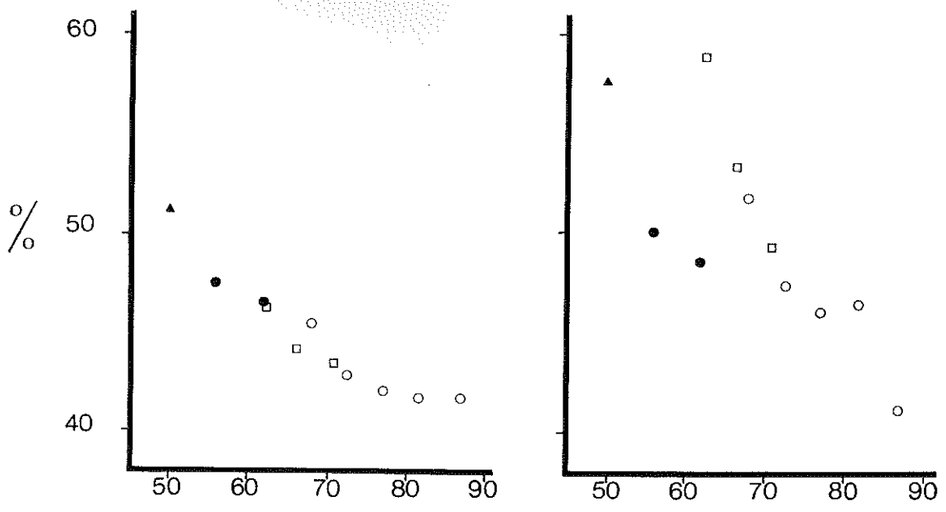

Figure 1. Changes in the mean polypeptide ratios $\frac{R}{R+S}$% (right) and $\frac{V}{V+T}$% (left) in free-ranging salmon of different mean length (cm). Closed symbols, grilse. Open symbols, non-grilse fish.

Symbols: Square—Greenland; Circle—Scotland; Triangle—Canada.

RESULTS

Figure 1 illustrates the ratios $\frac{R}{R+S}$ and $\frac{V}{V+T}$ in grilse, grilse-sized one sea-winter salmon and large salmon from Scotland and West Greenland. The ratio of $\frac{V}{V+T}$ is comparable in all three groups, the value declining smoothly over the total length range sampled. The ratio, $\frac{R}{R+S}$, however, is much less in grilse than in non-grilse one sea-winter salmon of similar size. In other words, the development of the haemoglobin pattern at the level of the constituent polypeptides is more advanced in grilse than in non-grilse fish, but only in the case of the R, S polypeptide pair. These data which are based on relatively large numbers of fish are summarised in Table 1.

The data for the cage-reared sample are presented in Figure 2. The trend for the ratios to decrease with increasing length of fish is evident in this sample also, although the scatter of points is high in both cases. Regression equations were calculated separately for the grilse and non-grilse components of these fish and these are presented in Table 2. The slopes of the regressions are statistically significant only in the grilse component, and the regression lines have been drawn in Figure 2. Although there is a trend towards lower values in the two ratios in non-grilse fish, this was not statistically significant. In addition, the grilse and non-grilse fish differ significantly in the slope of the regression for the $\frac{V}{V+T}$ ratio; for the regression of the $\frac{R}{R+S}$ ratio they do not differ in a statistically significant way. ($t64 = 1.853$; $.10>p>.05$).

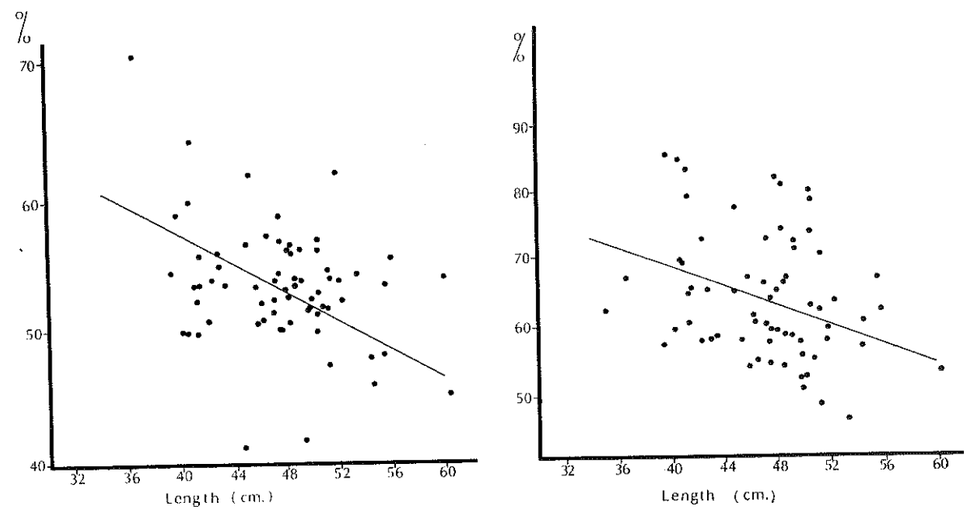

Figure 2. Changes in the polypeptide ratios $\frac{R}{R+S}$% (right) and $\frac{V}{V+T}$% (left) in cage-reared salmon. Regression lines have been fitted where these are statistically significant i.e. for grilse fish only.

DISCUSSION

It is apparent from the results presented here that the difference in haemoglobin pattern between grilse and non-grilse salmon of similar size reflects the greater development, at least within the R, S group, of the globin polypeptide ontogeny in grilse fish. This observation, obtained with free-ranging salmon, might also be attributable to factors other than grilse habit such as stock differences, location of capture or nutritional state. In this context the results of the Lettermullan fish, which are all from one river, of the same age and reared together for their entire life, are important. In these fish also the globin ratios change progressively with length. However, the change is statistically significant only in those fish classified on external features as grilse, and these exhibit rates of change greater than those of non-grilse fish of the same population and of similar size range. Within a single cohort, then, those fish which exhibit the grilse phenotype exhibit a higher rate of haemoglobin development, independently of length and chronological age, than those which do not. In non-grilse fish i.e. potential 2 sea-winter salmon, the timing of the first cycle of sexual maturation is delayed relative to grilse and the normal ontogenetic development of the haemoglobin is correspondingly retarded.

At this time it is not known if the different rate of haemoglobin development in grilse and non-grilse is a life-long process commencing early in the juvenile phase of the life cycle and extending to the immediate pre-maturation adult phase. If so, then analysis of the haemoglobin in parr and smolts, or early in the first sea-year, may be useful in identifying those stocks likely to produce a large grilse component. On the other hand, one may speculate that the accelerated haemoglobin development in grilse indicates that these individuals have responded, at the haemoglobin level, to some biochemical or physiological trigger which precedes and possibly initiates the cycle of sexual maturation. Thyroxine is one obvious biochemical candidate as a trigger chemical in this regard. Thyroxine is implicated in the development of sexual maturation and in the impetus to migration in many fish species including salmon (Woodhead, 1975). A surge of thyroxine which occurs in the spring months has been postulated to initiate the complex biochemical and physiological processes that lead to eventual sexual maturity in salmon. These processes are successfully initiated only in those individuals having a sufficiently low response threshold (Simpson and Thorpe, 1976). Thyroxine also accelerates the rate of haemoglobin development in salmon (Koch *et al* 1964). In this case, then, accelerated haemoglobin development may serve to identify those individuals which have responded to the thyroxine surge, at both the haemoglobin and sexual maturation levels.

Whether the accelerated haemoglobin development of grilse is a life-long or short period phenomenon, it is clear that some endogenous mechanism such as a lower response threshold to developmental triggers or a higher rate of physiological ageing, must exist which distinguishes potential grilse from potential non-grilse salmon within a single population.

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I am grateful to the Department of Agriculture and Fisheries for Scotland for permission to utilize the data on which Figure 1 and Table 1 are based. I thank the management and staff of Bradán Mara Teo. for permission to sample fish at Lettermullan and particularly Padraic de Bhaldraithe Uas. for his considerable help and advice. Adrian Wilkins assisted with the collection and preparation of the Lettermullan sample and Michael Murphy and Bernie Ashe have given invaluable assistance in this programme which is funded in part by the National Board for Science and Technology.

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Table 1. Summary of the mean values of the polypeptide ratios $\frac{R}{R+S}$% and $\frac{V}{V+T}$% in salmon of different length groups, spawning type and place of capture. The summary is based on haemoglobin data presented in Wilkins (1968).

	Place of capture	Number of fish	Mean length (cm)	$\frac{R}{R+S}$%	$\frac{V}{V+T}$%
Grilse	Canada	32	50.0	57.62	51.06
	Scotland	26	55.8	50.14	47.50
	Scotland	28	61.8	48.61	46.62
Non-Grilse	Greenland	34	62.4	58.90	46.28
one	Greenland	59	66.3	53.37	44.14
sea-winter	Greenland	20	71.1	49.40	43.43
Large	Scotland	18	67.9	51.91	45.56
Salmon	Scotland	32	72.3	47.53	42.93
>1 sea-winter	Scotland	60	77.2	46.18	42.10
	Scotland	35	81.7	46.55	41.66
	Scotland	11	86.8	41.34	41.74

Table 2. Regression of the ratios $\frac{R}{R+S}$% and $\frac{V}{V+T}$% on length for individual salmon of a single cohort grown together in sea-cages at Lettermullan, Co. Galway. Individuals were classified as "grilse" or "non-grilse" on the basis of external appearance. L = Total length in cm.

Fish type		Regression	S E of b	Probability b = 0	Probability bg = bng
$\frac{R}{R+S}$ Ratio					
	Grilse	Y = 98.9—0.745 L	± 0.232	.01	.10 > P > .05
	Non-Grilse	Y = 78.3—0.297 L	± 0.473	N.S.	
$\frac{V}{V+T}$ Ratio					
	Grilse	Y = 80.7—0.567 L	± 0.154	< .001	P < .02
	Non-Grilse	Y = 53.0—0.017 L	± 0.158	N.S.	

Development of rainbow trout farming in Ireland

by

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ABSTRACT

The expansion of commercial rainbow trout farming in Ireland from 5 freshwater units in 1967 to 15 freshwater and 5 marine units in 1980 is described. This expansion is associated with improved nutrition, predator control and treatment of diseases of parasitic and viral origin including *Octomitis* sp., *Myxosoma cerebralis* and Infectious Pancreatic Necrosis (IPN). Broodstock failure was examined and remedial measures involving the introduction of ova from additional sources proved successful. Escapement of rainbow trout from farms was shown to have no adverse effect on native fish populations. Preliminary examination of fish farm effluent has indicated that no serious pollution has been caused. Experiments are in progress to develop specific pathogen-free stocks.

INTRODUCTION

Commercial fin fish farming in Ireland is based on freshwater rainbow trout culture and, more recently, on salmon and rainbow trout culture in sea cages.

The Inland Fisheries Trust established a commercial rainbow trout farm at Roscrea in 1957. This operated as such until 1961 and demonstrated clearly the feasibility of rainbow trout culture under Irish conditions. In 1959 the Government established a pilot scheme to encourage freshwater fish farming. Six demonstration units were set up, constructed along traditional Danish pond culture lines, of which the main features were a gravity fed water supply to excavated earthen ponds draining into a central channel. Feeding was entirely on liver, waste fish and fish offal. By 1967 only one of the original six units remained in operation. It was apparent that the concept of fish farming as an adjunct to other farming activities on the scale envisaged was not an economic proposition.

In addition to the demonstration farms, four independent commercial units were established. The commercial unit at Waterville closed down early in 1967 and for the following five years only four farms out of the original ten remained in operation. From 1972 a steady increase in the number of farms in freshwater took place. In 1975 Bord Iascaigh Mhara started trials in sea-cages in Killary Harbour as did the Salmon Research Trust of Ireland and by the end of 1980 some 16 freshwater and 6 marine farms were producing rainbow trout. Production had increased from 87 tonnes in 1968 to a total of 402 tonnes in 1980 (Table 1).

Table 1. Numbers of rainbow trout farms and total sales production (tonnes) in Republic of Ireland.

Year	Freshwater farms		Marine farms	
	Number	Production	Number	Production
1968	4	87		
1969	4	105		
1970	4	81		
1971	4	129		
1972	4	146		
1973	5	266		
1974	5	215		
1975	6	226		
1976	6	171		
1977	7	215		
1978	12	240	2	7
1979	14	241	5	49
1980	16	269	6	133

NUTRITION

The scarcity of fish offal led to experiments with alternative feeds. These were conducted from 1965 to 1968 at the Aherlow fish farm using ponds 12m × 6m × 1m depth stocked with 6,000 and 4,000 fingerling. The results are summarised below; conversion rates expressed as units by weight of feed to produce one unit of weight gain of fish.

		Conversion rate Max.	Min.	Cost of fodder per tonne of fish
September 1967 —June 1968	Offal	17		£405—£445
	Imported pellet	1.20	1.37	£150—£200
October 1968 —May 1970	Imported pellet	1.25	2.10	£195
	Irish pellet	1.68	4.1	£109

The best conversion rate of 17:1 was achieved when using good quality offal at temperatures from 6° to 8°C. The rate deteriorated with increasing temperature and led to turbidity of pond water, accumulation of organic matter on the pond bottom and an outbreak of gill disease.

A poor conversion rate of the Irish manufactured pellet was observed at the beginning of the experiment. The manufacturers altered the constituents as the experiment proceeded and eventually achieved a satisfactory rate which, in conjunction with relatively low cost, resulted in the most economical source of fodder.

A significant advantage of the changeover to dry diets was the reduction in time taken to reach marketable size. In 1967 up to 30 months were required to clear the hatch in any one year. By 1969 roughly 50% reached saleable size (200g) in 15 to 18 months, a further 25% were cleared in 21 months and the balance in two years by which time the best of the following year's hatch were available.

LOSSES OF STOCK

Disease

Stocking rates at the eyed ova stage were high but subsequent losses at the advanced fry stage resulted in poor overall survival to market size from as little as 7.4% to just over 30%.

In 1969 an examination of survival rates at different stages of the life cycle confirmed that in general very little mortality is encountered in the hatching stages. Mortalities of 0.4% to 5% were recorded from the green to the eyed stage and less than 0.5% from the eyed to hatching stage. However, acute losses occurred in early feeding fry in the period May to July.

These losses were due in the main to parasitic diseases, *Octomitus* sp. and *Myxosoma cerebralis* (Hofer) and to bacterial gill disease. The latter was one of the major problems, often accounting for very heavy losses of fry and fingerling. Further losses were caused by a low virulence virus disease, infectious pancreatic necrosis (IPN).

Octomitus was normally successfully treated using calomel. The use of mercuric compounds has since been discontinued. Outbreaks of whirling disease, caused by *M. cerebralis*, are now avoided by all farmers by ensuring that fry are not stocked in earthen ponds until larger than 7cm. The use of concrete, asbestos or fibre-glass tanks or raceways for feeding the young fish is now standard hatchery practice.

Bacterial gill disease, formerly one of the most serious, was generally associated with poor husbandry, overcrowding and over-feeding during low flow periods. Chemical treatments with Hyamine 3500 or malachite green/formaline flush were very effective. However, the change to raceway type production systems, with rapid throughput of water, has reduced the incidence. When it does occur, manipulation of the water flows combined with cessation of feeding has proved a very effective method of controlling the disease.

Infectious pancreatic necrosis has caused serious losses from time to time, but generally in a situation where the fish have been subjected to stress of some kind. The virus strain endemic in most Irish fish farms was sero-typed at the Veterinary Research Laboratory in 1977 (D. O'Brien, pers. comm.) and found to be the avirulent Ab strain.

More recently, losses have been caused by a kidney disease (O'Brien, McArdle and Doyle, 1977) and by a previously unreported kidney condition in saltwater described by Doyle, McArdle and Smith (unpublished) as "nephrocalcinosis" in 1979 and 1980. A dietary cause was postulated. Two sea-cage installations have sustained serious losses in production associated with red tides.

Predation

One of the most startling facts to emerge during the early part of the nutritional trials at Aherlow was the very high incidence of unexplained losses of experimental fish. These amounted to 42% between November 1968 and May 1970. Of 31,500 fingerling stocked only 16,578 survived to be marketed.

Losses were identified as:

Accidental	2.30%
Casual mortality	0.97%
Unsaleable (deformed)	1.98%
Unexplained	42.6%

It was concluded that the unexplained losses resulted from predation, mainly by herons from a nearby heronry. Mink, otters and rats have also been observed. During the period the test fish ranged in weight from 50g to 250g. Theft was not considered a possibility as the farm was remotely situated and guarded by dogs.

BROOD STOCK INVESTIGATIONS

Following reports of outbreaks of new virus diseases (VHS, IHN) in European and North American fish farms in 1968, it was decided to impose a total ban on further imports of salmonid ova, to take effect from October 1971. It was therefore important to establish that domestic broodstocks were of sufficiently high quality to ensure that restocking requirements were capable of being met from within the country.

In the 1970/71 hatching season, a survey on the four main brood stocks was carried out, involving the examination of 587 hen fish, yielding some 1.2 million ova. Egg numbers were estimated by Von Bayer's method (Greenberg, 1960). Egg yields and survival to hatching are given below.

Age	Weight (g) of hen fish			Egg diameter (mm)	Yield/ per kg	Yield/ fish	Survival %
	Min.	Max.	Mean				
2	340	900	450	4.5—5.5	1868	768	85
3 and 4	450	2900	1800	4.5—5.5	1620	3001	85
4	1500	4000	2800	4.6—5.5	1151	3252	75
5 and 6	1500	2900	1800	4.6—5.8	1661	3134	25—75

In general, older brood fish had lower fecundities and bigger eggs, but up to 75% mortality was observed from 6 year old fish at their fourth successive stripping. The 3 and 4 year old fish gave the best results with low mortalities and high yields.

Fecundity studies continued until 1972 and confirmed the earlier results which showed considerable variation both in fecundity and in survival of ova. In 1972 a selective breeding programme for brood stocks was initiated on the farms at Aherlow and Thomastown. At Aherlow two-year-old fish from parents of known high fecundity were selected on the basis of good survival, fast growth and apparent resistance to disease. These gave excellent results with good fecundity, good fertility rates and low mortalities. At Thomastown two-year-old cocks were found to give excellent results while three-to five-year hens gave the best results in terms of size of fry and survival. Eggs from two-year hens at this farm were very small and fry survival was poor.

Unexpected failures in maintaining healthy brood stocks between 1974 and 1976 led to a renewal of imports of ova. These were confined to certified disease-free sources. Pilot studies commenced at the Glenties hatchery of the development of specific pathogen-free stocks. The fish introduced from the Isle of Man in 1976, Norway in 1977 and USA in 1978 were virus free and regular tests carried out at the Veterinary Research Laboratory from 1976 to 1979 confirmed this status. The Manx and Norwegian fish have been stripped in 1979, 1980 and 1981 and progeny supplied to other fish farms. Growth rate and details of age at maturation are now being studied to evaluate the potential for marine cultivation.

ENVIRONMENTAL IMPACT

Escapes

In 1971 the rivers adjoining four fish farms were electrofished above and below the outlets from each for distances of 1 to 3km to see what effect escapes of rainbows might have on the wild salmonids. All fish were counted and all, except rainbow trout and a representative sample of brown trout, were returned alive to their streams. In general the rainbow trout caught were small and, judging by flesh colour, were recent escapees. Details of numbers caught are given below:

Date	Location	Total catch	Percentage of rainbows in total catch
21—22 April	Aherlow	793	4.04
28—29 April	Goatsbridge	1,075	3.25
28—29 July	Dingle	320	5.00
24—25 August	Woodenbridge	260	0.38

Spot checks carried out further downstream at Aherlow and Goatsbridge failed to produce any rainbow trout. A further brief survey of portions of adjoining rivers upstream and downstream of the outfalls of the Aherlow and Goatsbridge farms in June 1973 confirmed the 1971 findings. In Mayo and Connemara rivers rainbow trout escaped from sea cages have been observed (D. J. Piggins pers. comm.).

Effluents

During the summer of 1971 effluents from the Aherlow and Dingle fish farms were analysed. Weekly BOD tests were made and samples of the invertebrate fauna were collected upstream and downstream over distances of 1000m. Effluents gave oxygen minima of >6ppm, ammonia maxima of <0.1 ppm and BOD <2.9 ppm. Following dilution by the receiving waters the levels rapidly returned to normal. Faunal studies indicated that recovery was completed after a distance of 500m downstream. Spot checks conducted periodically since 1971 confirmed that effluent water quality continued to be satisfactory.

Disease

The first report of the salmon disease, ulcerative dermal necrosis (UDN) came in 1964 from the Currane River which supplied a fish farm. This led to a popular belief that the disease had originated amongst the rainbow trout in the farm which had grown from imported ova. Carbery and Strickland (1968) were able to establish that rainbow trout did not show clinical signs of the disease nor did they act as symptomless carriers.

DISCUSSION

Development of rainbow trout farming, after a promising start in 1957, was slow until 1973. Inhibiting factors included the discovery that trout farming could not be satisfactorily pursued on a part-time basis as an adjunct to traditional farming and that waste fish products did not constitute cost effective fodder. The belief that UDN or other diseases might be introduced to wild stocks by fish farming enterprises, and that fish farm effluents would cause serious pollution, also discouraged expansion.

By 1973 pellets had become standard feed, the environmental risk had been demonstrated to be negligible and husbandry practices and disease control had improved to a great extent. The numbers of farms increased from 7 in 1977 to 22 in 1980, which included the establishment for the first time of salt-water cage rearing. It now appears that the major problems of husbandry, including feeding, health and breeding, are being successfully controlled.

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Nephrocalcinosis in freshwater and saltwater-farmed rainbow trout in Ireland

by

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ABSTRACT

In an extensive investigation into diseases of the kidney in farmed salmonids, nephrocalcinosis was the disease most frequently found. The histopathology of the disease, which is described, was found to differ significantly in saltwater and in freshwater-farmed rainbow trout. Results are presented of experiments which involved feeding defined diets to rainbow trout held in hard and in soft freshwaters, carried out to test the significance of diet and water quality in the aetiology of the disease.

INTRODUCTION

For the past two and a half years we have been investigating diseases of the kidney in farmed salmonids in Irish freshwater and marine farms. Nephrocalcinosis (NC) is the disease which we have most commonly found in both environments. NC is a chronic disease of rainbow trout characterised by degenerative changes and deposition of calcium salts in the kidney tissue (Besse et al. 1968; Herman, 1971; Landolt, 1975; Harrison and Richards, 1979; Schlotfeldt, 1980). The aetiology of the disease is still uncertain, though it is considered that dietary and environmental factors may be involved (Besse et al. 1968; Herman, 1971; Landolt, 1975) and there is evidence implicating magnesium levels in foods (Cowey et al. 1977) and carbon dioxide levels in the water (Harrison and Richards 1979; Smart et al. 1979; Eddy et al 1979). The disease was first recorded in Ireland in 1977 by O'Brien et al.

MATERIALS AND METHODS

In the first year of the study a broad screening programme was carried out in which freshwater and marine rainbow trout farms were sampled, some on more than one occasion. In the second and third years, fish from the supply hatcheries were screened first, and subsequently the farms to which they had been supplied. In all 16 of the country's 21 freshwater farms and nine of the eleven marine stations were sampled over the period of study.

Detailed information on farm management, food and feeding regimes, disease record, drug use etc. was gathered, and water quality on freshwater farms determined by analysis.

Rainbow trout were sampled, anaesthetised and killed in MS222, and examined externally and internally for macroscopic lesions. Tissues were fixed in 10% formol saline and processed by routine histological methods. Sections were stained with haematoxylin and eosin (H & E), and Von Kossa and Alizarin Red-S (Johnson, 1972) for calcium. The histopathology of anterior, mid- and posterior kidney of each fish was examined in detail, together with that of any other tissues where lesions were suspected.

RESULTS

Nephrocalcinosis was found in eight freshwater farms where 30/121 fish (25%) were affected and in nine marine farms where 40/109 (37%) fish were affected.

The disease was diagnosed by histopathology. Contrary to views expressed elsewhere, we did not find that macroscopic changes in the kidney, such as white streaks, "grittiness" or swelling to be reliable indicators of the disease: on only one occasion did a macroscopically obvious white ureter correspond to a histopathological diagnosis of nephrocalcinosis. Other non-specific changes noted were darkening in colour and abdominal swelling.

The histopathology of nephrocalcinosis in sea-farmed fish was generally in agreement with the previously published descriptions of Landolt (1975) and of Harrison and Richards (1979). The most obvious feature was the presence of calcium-associated cast-materials in renal tubules and ducts. These were accompanied by degenerative changes in the tubules, with pyknosis, vacuolation of cells, stretching of the tubules and separation of the epithelial cells, and often, fibrosis of these degenerate kidney elements. Granulomas had frequently formed around cell debris and calcium casts. Only on occasion were calcium deposits located in the melanomacrophage centres in the marine fish (Figs. 1 and 2, see end paper for figures).

In contrast with the observations of Harrison and Richards (1979), calcium deposition in freshwater trout occurred primarily in the melanomacrophage centres, and only a minority of deposits occurred within tubules. These deposits ranged from small, unencapsulated calculi, distinguishable within the melanin-bearing areas (Fig. 3), to larger deposits surrounded by some fibrous cells, to deposits within granulomas which deformed the melanomacrophage centres.

In order to quantify the differing patterns of calcium deposition in the freshwater and in the marine environment, the number of deposits observed in each fish in one cross section each of anterior, mid and posterior kidney was counted, and the location of the deposits was scored under three headings: "tubule" where a calcium deposit occurred within a kidney tubule or duct; "centre" where the deposit occurred in a melanomacrophage centre; and "uncertain" where there was any uncertainty as happened where severe degeneration had occurred, or where extensive granuloma formation had obscured the origin. The results are shown in Table 1.

Table 1. Deposition of calcium in melanomacrophage centres and in tubules in the kidneys of rainbow trout sampled 1979-1981.

	Number of fish screened	Number of fish with NC	Total number of Ca++ deposits in NC affected kidneys	Tubules	Centre	Uncertain
Marine farms	109	40	1653 (100%)	1288 (78%)	296 (18%)	69 (4%)
Freshwater farms	121	30	580 (100%)	55 (9%)	484 (83%)	41 (7%)

The aetiology of nephrocalcinosis is not yet known. In our study, as in others, no bacterium was consistently associated with the disease. Besse et al. (1968), Herman (1971) and Landolt (1975) attribute a nutritional basis to the disease. Cowey et al. (1977) report an association between the disease and low magnesium levels in food. In Ireland, it was widely believed by fish farmers that food was a major contributing factor. In order to test this assumption a series of feeding trials were undertaken. A common stock of 1+ rainbow trout was introduced into two freshwater farms, one hard water, farm W, and one soft water farm, farm C. On each farm separate ponds of fish were fed aliquots of the three commercially available diets X, Y, and Z. Water quality parameters including CO_2 concentrations were assessed. Growth, condition, and % spleen weight were calculated and detailed histopathology of the anterior, mid and posterior kidney were examined on each of six fish from each of the six experimental ponds every two weeks over the three month period. Foodstuffs were analysed, and compared at the start and at the end of the experiment for moisture, ash, total protein, 12% TCA-soluble nitrogen, fat, tribarbituric acid, phosphorus, calcium, magnesium and free fatty acids.

Some calcium deposition was found in the kidney on both farms, but it was significantly more severe in fish from farm W than in those from farm C (Table 2).

Table 2. Calcium deposits in the kidneys of 213 fish sampled during 3-month feeding trials.

	Farm C			Farm W		
Total number of fish sampled	107			106		
Total number of Ca++ Deposits	159			1392		
Food Type	X	Y	Z	X	Y	Z
Number of Ca++ deposits	32	99	28	259	529	604
Number of affected fish	8	13	10	21	14	22

It is evident from Table 2 that calcium deposition occurred in rainbow trout fed on each of the three feeds. No significant distinction could be made between food types X, Y and Z on the basis of the incidence of renal calcium deposition on either farm C or farm W. However, a significant difference ($P < 0.001$) was found between farms in the degree of renal calcium deposition. Thus the severity of nephrocalcinosis appeared to be influenced by farm-related factors rather than by diet. However, it was not possible to correlate the severity of the disease with any one of the on-farm environmental factors monitored during the feeding trials.

Calcium deposition and nephrocalcinosis observed in this study did not affect growth: the mean condition factor for the three most severely affected fish on farm C was 1.44 ± 0.14 compared with a value of 1.30 ± 0.01 for farm C fish as a whole; while the mean condition factor for the 16 most severely affected fish on farm W was 1.29 ± 0.17 compared with a value of 1.32 ± 0.03 for farm W fish as a whole.

DISCUSSION

Nephrocalcinosis is a disease which occurs in rainbow trout. Despite the fact that it does not usually cause death directly, and does not inhibit growth unless extremely severe, it does render fish relatively more susceptible to stress of any kind, leading to indirect mortality.

In the present study nephrocalcinosis and associated mortalities were found to be more severe on marine than on freshwater farms. We attribute this to the differing histopathological manifestations of the disease in the two environments. In freshwater, calcium deposition is mainly associated with the melanomacrophage centres, which appear to contain it in such a way as to minimise renal damage. In saltwater fish, on the other hand, the deposition is primarily tubular and this leads to extensive damage including tubular distension and obstruction, with associated necrosis, fibrosis and granuloma formation.

The feeding experiments conducted to test the role of diet in the aetiology of NC showed that the feeds commercially available in Ireland in 1980 did not, over a period of three months, induce nephrocalcinosis in 1+ rainbow trout, but suggested rather that renal calcium deposition was influenced by unidentified farm-related factors. Because of the relatively greater severity of NC on marine than on freshwater farms in Ireland, comparable feeding experiments to test the possible role of diet in NC in marine-farmed fish are now being undertaken.

Our detailed study of the histopathology of NC leads us to believe that calcium deposition, which is a diagnostic feature of the disease, may in fact be a secondary phenomenon, occurring by accretion to necrotic cell debris or to abnormal metabolic products accumulated in the renal tissue.

It is known that necrotic cellular debris has an affinity for calcium salts (Harrison and Richards, 1979). We have frequently observed necrotic cell debris sloughed into kidney tubules within degenerate kidneys in the absence of calcium deposition; we have also demonstrated an organic matrix within the renal calculi following removal of calcium prior to histological staining. Gillespie and Evans (1979) analysed the chemical composition of calculi from NC and concluded that the mineral deposits formed a network on a ceroid base.

We have come to view NC therefore as a disease which may be initiated by a variety of aetiological 'insults' any one, or group of which, causes either necrosis of renal cells, or deposition in the kidney of excess metabolic products. Such 'insults' or stresses could include: high environmental CO_2, for which there is evidence as an aetiological factor in NC (Smart et al. 1979; Eddy et al. 1979); or unsuitable diet as suggested by Besse et al. 1968, Landolt, 1975 and Cowey et al. 1977, though not found by us in our feeding trials; or excessive osmotic stress due to one-stage transfer fresh to saltwater; or perhaps even in some instances bacterial or viral infection involving renal necrosis. We found, as have other investigators previously, no consistent association between NC and any one micropathogen, (Wunder, 1967; Landolt, 1975).

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The leucocytes of the pike *Esox lucius* L.

by

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ABSTRACT

A study of the blood of fish is ongoing, primarily because of the potential use of fish blood parameters as indicators of health and disease, and because of the need to understand the fish immune system. The structure, ultrastructure, development and functions of the white blood cells are being investigated.

This paper describes the morphology of the cells of circulating blood and haemopoeitic tissue as seen by light microscopy. The cells are defined not only by description but also by colour photomicrographs, because of the ambiguity of written description and the confusion in the literature in fish blood cell nomenclature.

INTRODUCTION

There is ever increasing interest in the blood of fishes in recent years due particularly to the potential use of fish haematology as a tool in fish management and fish pathology and also to the rapid growth of comparative immunology.

Mulcahy (1970) recorded the blood values of the healthy northern pike *Esox lucius* L. as part of an investigation into a high incidence malignant epizootic lymphoma which occurs in that species in Ireland. The parameters measured were haematocrit, red cell count, total white cell count, differential white cell count, red/white cell ratio, red cell fragility, haemoglobin level, serum protein concentration, and serum electrophoretic patterns on cellulose acetate and polyacrylamide gel. The differential white cell count distinguished only between lymphocytes and other leucocytes.

Considerable confusion exists in the literature in relation to fish leucocytes. This is due partly to lack of agreement in terminology and partly to lack of standard methodology; in addition some of the descriptions of leucocyte morphology are not precise enough to be unambiguous. A number of the more recent papers recognise this confusion and make constructive proposals for development and standardisation. Ellis (1977) has rightly pointed out that standard terminology will only develop when morphological, ontogenetic and functional data are in agreement. Research is moving in these directions but it will be a number of years before this situation is achieved.

A study of the leucocytes of the pike is presented here, through colour photomicrographs as well as descriptions to avoid ambiguity, and to provide a reference which it is felt will be useful to other workers in the field.

MATERIALS AND METHODS

Adult pike were obtained by electro-fishing and netting, and were kept in large well-aerated tanks in order to stabilise for a minimum of a week.

Blood was removed from the heart and initially either heparin (13-16 mg/ml) or EDTA (0.2 mg/ml) was used as anticoagulant. Heparin may markedly alter the staining affinity of fish blood cells (Ellis, 1977), and in this study EDTA was found to give better quality staining than heparin. All photomicrographs and descriptions therefore refer to EDTA-treated blood. Portions of the anterior, mid, and posterior kidney and spleen were removed, and imprints were made according to Ashley and Smith (1963).

Tissue imprints and peripheral blood films were examined using four stains: Wright-Giemsa (Romansky), Peroxidase, Sudan Black B and Periodic Acid Schiff (PAS) (Hayhoe *et al* 1969). Differential leucocyte counts and cell sizes were determined from Wright-Giemsa preparations. Cytochemical reactions were scored accoridng to positivity. Photographs were made with a Zeiss-Nikon camera using CB12 filter and Kodak CL135 film.

RESULTS

Note that plate numbers refer to frontispiece.

The following cells routinely occur in the normal circulating blood of pike: Mature and immature erythrocytes, mature and immature granulocytes, lymphocytes, thrombocytes, and monocytes. Plasma cells are rarely seen. Unless otherwise stated the following descriptions are based on Romanowsky stained cells.

The erythrocyte is the most obvious and distinctive cell type. It is an ellipsoidal cell (Plate 1), measuring 7 × 14 μm (Table 1). The nucleus is round or ovoid with compact dense chromatin. The cytoplasm is clear and pale grey-blue in colour. Immature forms are common and differ from the mature in that they are more rounded, the cytoplasm is very pale-staining and the nuclear chromatin is more loosely arranged.

Table 1. Sizes of peripheral blood cells of the pike.

Cell	Range (μm)	Average (μm)	Number of Cells
Erthrocyte	5 x 13—8 x 14	7 x 14	25
Large lymphocyte	7—17	9	300
Small lymphocyte	3—6	5	300
Round thrombocyte	2—6	5	100
Spindle thrombocyte	2 x 8—4 x 20	2 x 12	200
Early granulocyte	6—14	9	100
Maturing granulocyte	6—12	9	100
Band form granulocyte	6—10	9	100
Mature granulocyte	6—12	8	50
Monocyte	7—17	11	200

Granulocytic series: the early granulocyte, maturing granulocyte and mature polymorphonuclear granulocyte are distinctive in their form and staining reactions and form 0-64% (average 4%) of the leucocytes (Table 2). The early granulocyte is a round cell 9 μm in diameter (Plate 2), with an eccentric nucleus which is usually round but may be indented; the cytoplasm is pale-staining with bluish granules, the nucleus is deep purple with evenly-clumped chromatin. As the cell matures the nucleus becomes elongated and indented producing a "band-form". In the mature granulocyte the nucleus forms 2-3 lobes and the cytoplasm is clearly granular (Plate 3).

Table 2. Differential leucocyte counts.

Cell	Range %	Average %	Number of Samples
Lymphocytes	14—92	51	100
Thrombocytes	3—80	42	100
Immature granulocytes	0—64	3	100
Mature granulocytes	0—28	1	100
Monocytes	0—17	3	100

The cells of the granulocytic series all reacted positively with Sudan Black, PAS and peroxidase stains. The more mature the cells the denser the granules in the cytoplasm with Sudan Black (Plate 4). The PAS reaction varied from faintly positive to strongly positive depending on the maturity of the cell (Plate 5). The peroxidase reaction was faintly positive and faded rapidly.

Lymphocytes formed from 14-92% (average 51%) of the leucocytes, the size range was 3-17 μm. In this study the division of lymphocytes into "small" and "large" was initially adopted for convenience as it facilitated both counting and differentiation from round thrombocytes; the distinction does not reflect any known functional difference but an analysis of the frequency of size distribution reinforces the likelihood that two populations of lymphocytes exist (Fig. 1). The lymphocyte has a round central nucleus with even chromatin pattern, and a thin, often uneven rim of clear deep-blue cytoplasm which sometimes showed pseudopodia. (Plates 6 and 7).

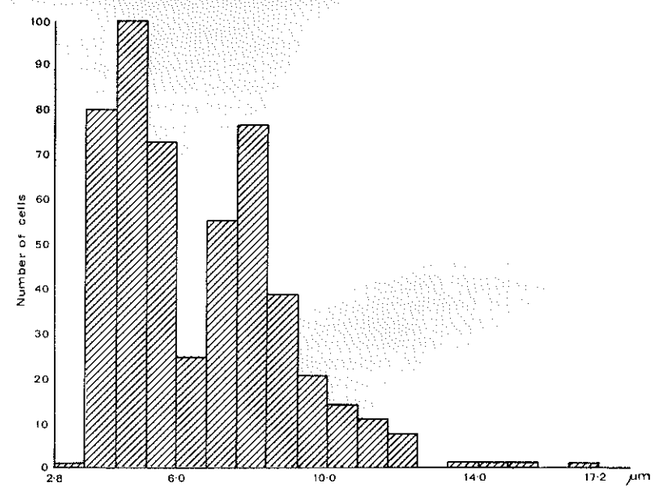

Figure 1. Size distribution of 500 lymphocytes.

The thrombocytes which are of primary importance in clotting, occur in two distinct and interchangeable forms with various intermediate stages commonly visible (Plate 8). Thrombocytes formed an average of 42% of the leucocytes; (Table 2) range 3%-80%. Spindle shaped thrombocytes (3 × 13 μm) are predominant: the ovoid nucleus is deep purple with dense chromatin; the cytoplasm which may be drawn out into a fine point at either pole is sparse, and very clear pale blue without cytoplasmic granules. These spindle cells can round up to form compact spherical cells 5 μm in diameter with a dense purple nucleus often with chromatin clumped in a "cartwheel" pattern, and a thin rim of blue/purple staining cytoplasm. Rounding of the thrombocyte is enhanced by stress to the fish, but rounded thrombocytes are seen regularly even in healthy unstressed pike. In the rounded form the thrombocyte is often difficult to distinguish from a small lymphocyte.

Monocytes form from 0-17% of the circulating leucocytes, the average value is 3%. The monocyte is a relatively large (7 μm—17 μm) round cell with an eccentric nucleus which is often distorted or indented. The cytoplasm is an uneven deep blue often with irregular outlines and often vacuolated with ingested material. (Plate 9).

Plasma cells occur, but only rarely. They are ovoid; the nucleus is round and ecentric and the chromatin is evenly patterned. The cytoplasm is clear dark blue with a prominent pale staining horseshoe-shaped "hof" next to the nucleus.

Haemopoeitic tissue

With the Klontz' *et al* (1964) haemopoeitic model based on the rainbow trout in mind, examination of Wright-Giemsa stained imprints of the anterior, mid and posterior kidney and the spleen, allowed clear identification of the following haemopoeitic cells: the large lymphoid haemoblast, small lymphoid haemoblast, the lymphoblast/erythroblast, the prolymphocyte and the proerythrocyte. The haemocytoblast as described by Klontz was not identified in any of the tissues examined. Mature erythrocytes and leucocytes were also present. It was not possible to classify clearly many of the transitional developing cells present.

The large lymphoid haemoblast, precursor of the granulocytic series, is one of the largest cells seen varying from 12-24 μm, average 15 μm. It is a round or ovoid cell with an irregular eccentric nucleus. The nucleus stains purple and chromatin is fairly open and unevenly clumped; the cytoplasm is blue-staining and may be finely granular (Plate 10, Table 3).

Table 3. Sizes of haemopoietic cells.

Cell	Range (μm)	Average (μm)	Number of Cells
Large Lymphoid Haemoblast	12—24	15	25
Small Lymphoid Haemoblast	8—15	11	25
Pro-lymphocyte	6—9	8	25
Pro-erythrocytes	6—15	9	25
Lymphoblast/erythroblast	7—14	10	25

The small lymphoid haemoblast, precursor of the erythrocytic series, the lymphocytes and the thrombocytes varies from 8-15 μm with an average size of 11 μm. It is a round cell with a central round nucleus. The nucleus stains deep purple and the chromatin shows an even pattern; the cytoplasm is an uneven deep blue. (Plate 11).

It was not possible to distinguish the lymphoblast from the erythroblast. The lymphoblast/erythroblast is a round cell 7-14 μm in diameter average 10 μm with a central round nucleus. The nucleus stains deep purple and the nuclear chromatin is dense; the cytoplasm stains very deep blue. (Plate 12).

The prolymphocyte is the first lymphoid cell clearly distinguishable from the erythrocytic series. It varies from 6-9 μm average 8 μm. The nucleus, which is very slightly eccentric is more loosely arranged than that of the mature lymphocyte. The surrounding cytoplasm is a clear deep blue (Plate 13).

The proerythrocyte varies from 6-15 μm with an average diameter of 9 μm. It is a round cell with a round central nucleus. The nucleus is a deep smooth purple; the cytoplasm deep blue to purple. This cell type is particularly prominent in imprints of the spleen (Plate 14).

Judging by the types of cell observed and the predominant cell type for each particular tissue it would appear that the major site of adult pike haematopoeisis is in the anterior kidney. The spleen appears to be primarily concerned with erythropoeisis, with some lymphopoeisis.

DISCUSSION

The erythrocytes in circulating pike blood, are readily distinguished, and conform to the descriptions of erythrocytes for other species in the literature. It is worth noting that the occurrence of immature red cells in the circulating blood is not abnormal: such cells were regularly seen in small numbers in the blood of the healthy pike.

Quite apart from the confused state of leucocyte nomenclature, there appears from the literature to be variation from one species of teleost to another in the occurrence and form of the leucocytes. In the pike all stages of granulocyte from immature to three-lobed mature forms were seen. This is similar to Conroy's (1972) findings in Atlantic salmon of metamyelocyte (immature granulocyte) juvenile neutrophil, band neutrophil and adult or segmented neutrophil. Similar cells have been described by Williams and Warner (1976) for the channel catfish. On the other hand polymorphonuclear cells were not seen in the blood of *Tilapia* by Ezzat et al (1974) while in the plaice the granulocyte nucleus is found to be irregular but not multilobed (Ferguson 1976; Ellis 1976). Barber and Westermann (1978) report pike blood cells as PAS-negative; however we found definite PAS positivity in marine granulocytes, provided smears of fresh blood were stained and examined without delay.

Interspecies differences in histochemical reactions in neutrophils are known amongst mammals (Sieracki 1955). The positivity of neutrophils for Sudan Black B has been demonstrated for some teleost species. Ellis (1976) reports plaice neutrophils as PAS and Sudan Black B positive. Blaxhall and Daisley (1973) found an increased sudanophilia from immature to mature granulocytes for the brown trout *Salmo trutta*. Sudan Black staining was found to be particularly useful, as a confirmatory stain for the pike granulocytic cells. It produced dense black granules in the cytoplasm, and the reaction was strongest in the most mature cells. The stain has the advantage of retaining its colour for some time; furthermore it can be superimposed on Romansky-stained films. The peroxidase reaction was less useful as it was only weakly positive in granulocytic cells and the colouration faded rapidly.

Eosinophils or basophils were not observed in pike blood in this study, nor by Barber and Westermann (1978). They have been recorded for other species; Conroy (1972) for example found the eosinophil to be the most common coarse granulocyte in salmon. Gardner and Yevich (1969) considered the eosinophil to be the only granulocyte present in cyprinodonts: this however seems to be an exceptional case. Eosinophils and basophils have both been found in the blood of *Tilapia zilli* (Ezzat *et al*, 1974) and *Ictalurus punctatus* (Williams and Warner 1976). Williams and Warner point out that these cells do not occur in most fish species.

While most lymphocytes and thrombocytes could be clearly differentiated in this study it was not always possible to distinguish with certainty the smaller lymphocytes from rounded thrombocytes. In blood smears from healthy unstressed pike round thrombocytes are regularly found, but their number increases with stress. This is an area where clarification is urgently needed, and the development of simple methods of differentiating between these cells would allow considerable progress in fish haematology, and facilitate its application to fish pathology. Ferguson (1976) distinguished the thrombocyte from the lymphocyte in the plaice: electron-microscope studies indicated that the thrombocyte had a characteristic "cross hatched" nuclear chromatin pattern and prominent vesicles lined with a "fuzzy coat". Ellis (1976) referred to four categories of thrombocyte in plaice: "spiked". "spindle", "ovoid" and "lone nucleus" forms. In the pike thrombocytes occurred in two distinct and interchangeable forms, spindle and round. The spindle form was equivalent to the plaice spindle cell described by Ellis, but the round thrombocyte, while similar to Ellis' "lone nucleus" type nevertheless had distinct though scanty cytoplasm which was usually smooth in outline. Ellis (1976) has specifically stained live lymphocytes of plaice by immunofluorescence and recommends the method as an accurate way of distinguishing between lymphocytes and thrombocytes.

Following the recommendations of the International Conference on Mononuclear Phagocytosis in 1970, Ellis (1977) considered the monocyte as an appropriate term for a population of white corpuscles in the plaice blood, the term macrophage being reserved for monocyte derived tissue phagocytes. This terminology has been adhered to in this paper. Monocytes were readily identified in stained smears. Plasma cells were occasionally seen.

The degree of variation in leucocyte differential counts in the blood of healthy pike is extremely wide (Table 2). For this reason, as previously emphasised, (Mulcahy, 1970), observations on individual fish are useless unless seen against a control background of many healthy fish.

The major site of haemopoeisis in the adult healthy pike is the kidney, particularly the anterior kidney. Erythropoeisis with some lymphopoeisis occurs also in the spleen. Klontz' (1964) rainbow trout model for teleost haematopoeisis proved a valid standard for the cells observed in pike haematopoeitic tissue, with the exception that the haemocytoblast was not identified in any of the tissues examined.

Investigations into the ultrastructure, development and functions of the pike leucocytes, are continuing.

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Studies in latent furunculosis

by

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ABSTRACT

The occurrence of latent furunculosis in hatchery-reared salmon *Salmo salar* was investigated. Administration of prednisalone acetate and heat stress was used to detect the latent state. Two year classes 0+ and 1+ were sampled monthly for a year. Carrier frequency in the 1+ fish rose from 55% in January to 100% in early summer and fell to 50% during the autumn. The studies of 0+ fish show that the carrier state can be established in the absence of clinical infection and may be of short duration.

INTRODUCTION

Furunculosis is one of the most serious diseases of farmed salmonids in Ireland. The causative agent is a gram negative bacterium, *Aeromonas salmonicida.* It can cause serious mortalities, 40% being recorded on one sea farm during one epizootic (Drinan *et al.*, 1978). Furunculosis exists in the clinical form and also has an asymptomatic carrier or latent state. The latent state is important for several reasons: there is the danger of spreading the disease by the transfer of apparently healthy infected fish between rivers; in salmon, the stress of seawater transfer can precipitate the disease causing large losses (Drinan *et al.*, 1978). The latent state may also have importance to the development of suitable vaccination procedures (Palmer and Smith, 1980; Jensen and Larsen, 1980).

The disease state can be induced from carriers under controlled laboratory conditions by the injection of corticosteroids combined with heat stress (Bullock and Stuckey, 1975; McCarthy, 1977). McCarthy (1977), working with brown trout *Salmo trutta,* found that the carrier rate did not differ significantly throughout the year. Sampling at different times through a 12-month period he found a high carrier rate throughout. Jensen and Larsen (1980), however, using brown trout and rainbow trout *Salmo gairdneri* Richardson sampled once in summer and once in winter and found that carrier fish occurred only in the summer period. Any variation could be of critical importance in the timing of transfer or the vaccination of fish. This paper describes seasonal variation in the frequency of carriers in hatchery-reared salmon.

MATERIALS AND METHODS

The experiments reported here were carried out on fish being reared in ponds at the Electricity Supply Board's (ESB) Parteen Hatchery. This hatchery has reported yearly furunculosis epizootics. Two year-classes of Atlantic salmon *(Salmo salar)* were sampled monthly, 1+ (fish > one-year old) and 0+ (pre-yearling fish).

Fish were transported from the hatchery, held in holding tanks and acclimatized at 11°C prior to commencing the experiments. At each sampling time, 20 fish were injected intramuscularly with 20 mg/kg of a corticosteroid, prednisolone acetate ('Deltastab', Boots Ltd., Nottingham) and held in individual tanks at 18°C for 2 weeks (McCarthy, 1977). Kidney material from any mortalities was streaked on Tryptone Soya Agar (Oxoid) and cultured at 22°C. Isolates were identified by standard biochemical tests and confirmed by agglutination with specific antisera. Mortalities in the ponds from which the samples were taken were recorded by the hatchery staff on a daily basis.

RESULTS

The frequency of carrier fish in the monthly samples of the 1+ salmon was determined from January 1980 to February 1981 (Figure 1). In January 1980 55% of the fish were carriers, the frequency then rose to a peak of 100% in April and subsequently declined to 45% in September. A second rise in the frequency of carriers occurred reaching a peak of 70% in December. Despite the small sample size the rise in April was significant at the 95% level; the December rise was not signifi-

cant at this level. The mortalities in the sibling fish remaining at Parteen showed a similar peak in April-May which declined to insignificant levels by October. No second rise in mortalities occurred in December to coincide with the rise in the frequency of carrier fish.

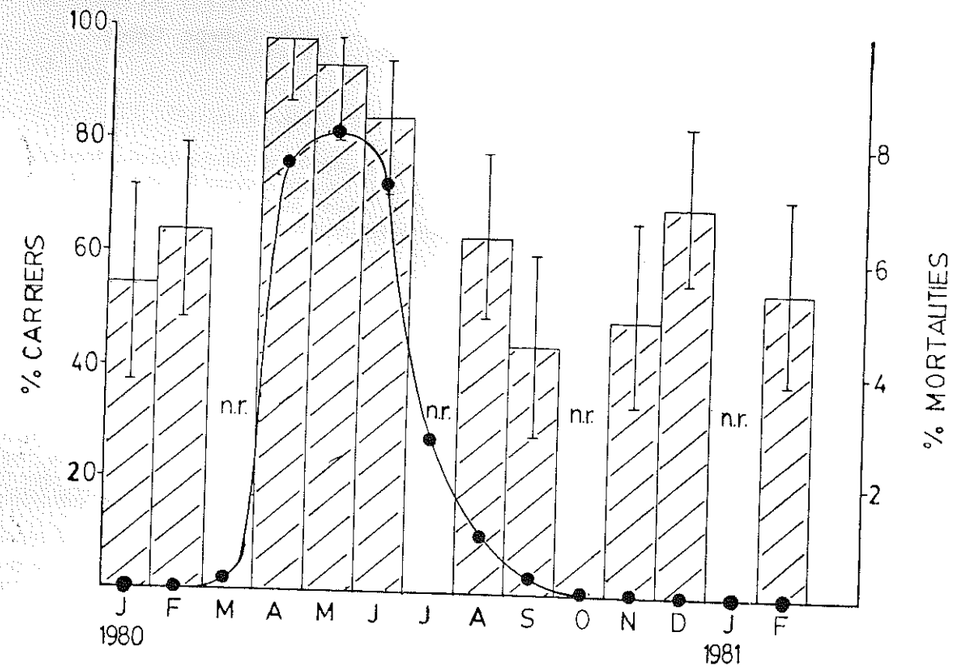

Figure 1. Frequency of carriers (histogram) of furunculosis and mortalities (curve) in farm controls in 1+ salmon. Bars represent 95% confidence limits. N.R. = No Result.

The frequency of carrier fish in the 0+ fish was determined between August 1980 and February 1981. No carriers were detected in these fish until December 1980 when a 45% level of carriage was detected (Figure 2). This frequency then declined and in February 1981 no carriers were detected. This rise and fall in the carrier frequency was significant at the 95% level. These 0+ fish samples were taken from a pond which experienced no deaths due to furunculosis either prior to or during the experimental period.

DISCUSSION

The data presented in this paper show that the frequency of carriers of furunculosis did fluctuate during the period of this study. The demonstration of a statistically significant fall in the frequency of carriers in both populations of fish studied, indicate that fish detected as carriers of furunculosis are capable of complete recovery from such infections. It should, however, be noted that the techniques used in this study only determined the frequency of carriers of furunculosis. They could not distinguish whether the carriers were suffering from an infection which would have led to the death of the fish, an infection from which the fish would have naturally recovered or a true chronic latent infection which has been reported to persist for up to four years. The mortalities in the fish left in Parteen indicate the frequency of fish undergoing lethal infections. As the highest cumulative monthly mortality during the study was 8%, it can be assumed that the majority of the fish detected as carriers in these experiments represent either fish with non-lethal, sub-clinical infections or those with true latent infections. Experiments designed to distinguish these two categories are planned for 1981-82.

Any attempts to generalise from one year's data is hazardous but it is perhaps possible to suggest reasons for the rises in carrier frequency shown in Figs. 1 and 2. The rise in carrier frequency in the 1+ fish in April coincides with the rise in water temperature (6.5°C on 1st April to 11°C by the end of the month) and a dramatic rise in mortalities in the pond-held population. Thus, it is plausible to suggest that the rapid rise in temperature during this month stressed some of the fish with latent

infection and these fish on dying released large numbers of *Aeromonas salmonicida* into the water. These bacteria subsequently infected all the fish in the pond giving a 100% carrier rate. The rise in carrier frequency in the 1+ fish during December 1980 was not significant at the 95% level.

However, the occurrence of a significant rise in the 0+ fish (Fig. 2) and in the third group of fish in the hatchery (unpublished data) suggest the rise detected in the 1+ fish was not purely due to sampling error. This rise in December cannot be caused by bacteria released by fish dying in the hatchery as no significant mortalities occurred during November or December in any fish held in the hatchery. The rise does, however, coincide with the movement upstream of hatchery-reared fish returning from the sea. These fish characteristically delay their movement past the hatchery water intake until late November or early December. Although it has not been experimentally confirmed, it is reasonable to assume that a significant percentage of these returning fish carry latent infections and therefore they represent a possible source of bacteria to induce the rise in carrier frequency detected in the hatchery-held fish in December.

It is hoped that the work planned for 1981-82 will further elucidate the epidemiology of latent furunculosis.

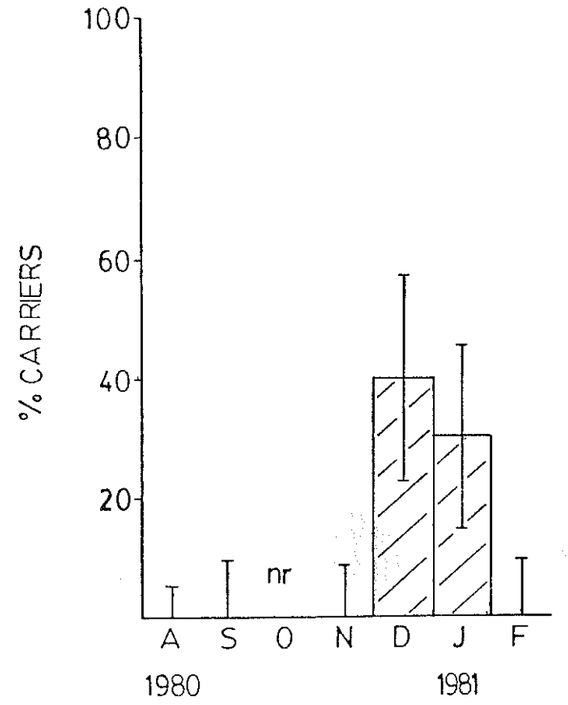

Figure 2. Frequency of carriers of furunculosis in 0+ salmon. Bars represent 95% confidence limits. N.R. = No Result. No mortalities were experienced by the control fish.

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Lymphoma in pike *Esox lucius* L. in Ireland: A review

by

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Lymphoma, a malignant neoplasm occurs in the pike in Ireland, and has been the subject of ongoing study.

The disease occurs in high frequency epizootics. It takes the form of soft, pink, highly-invasive tumours, which start usually in the jaws, flank or fins and spread inwards to involve the viscera. The histopathology and ultrastructure of the tumours has been described. The tumours have been transplanted using whole cells, and have been transmitted to healthy pike by cell-free filtrates indicating a viral aetiology. The epizootiology of the disease has been studied. Because the frequency of occurrence of the disease is so high relative to that in the rest of the natural range of the pike species, the genetic status of the Irish pike populations and its relationship to pike from northern-European countries and from North America have been investigated by biochemical methods. Current studies focus on the chromosomes of the pike and the tumour, and also on the possible aetiological significance of water pollution in the disease.

The results of these studies relate to an understanding of the biology of cancer, to the biology of the pike and to the management of pike as a sport fish in Ireland.

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PROCEEDINGS

23 April, 1981.

Welcome address : Professor P. MacCana,
President, Royal Irish Academy.

Introductory speech : Mr. P. Power, T.D.,
Minister for Fisheries and Forestry.

SESSION 1. *ECOLOGICAL STUDIES.*

Chairman : Dr. F. A. Gibson,
Inspector and Scientific Adviser,
Department of Fisheries and Forestry.

CARP *CYPRINUS CARPIO* L. IN IRELAND

P. Fitzmaurice, Central Fisheries Board.

MIGRATORY PATTERNS OF BREAM *ABRAMIS BRAMA* L. SHOALS IN THE RIVER SUCK SYSTEM

Kenneth F. Whelan, Central Fisheries Board.

THE IMPACT OF ARTERIAL DRAINAGE ON FISH STOCKS IN THE TRIMBLESTOW RIVER

D. T. McCarthy, Department of Fisheries and Forestry.

SOME OBSERVATIONS ON SALMONID ECOLOGY IN UPLAND STREAMS

G. J. A. Kennedy, Department of Agriculture for Northern Ireland.

GOBIESOCIDAE OCCURRING IN THE COASTAL WATERS OF CONNEMARA

James Dunne, University College, Galway.

THE LEUCOCYTES OF THE PIKE *ESOX LUCIUS* L.

A. G. Savage, Maire F. Mulcahy, and N. M. Casey, University College, Cork.

SESSION 2. *STOCK ASSESSMENT.*

Chairman : Dr. J. Bracken,
Senior lecturer in Zoology,
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POPULATION ESTIMATION OF JUVENILE SALMONIDAE

J. Browne, Department of Fisheries and Forestry.

A TECHNIQUE FOR ESTIMATING BROWN TROUT *SALMO TRUTTA* L. POPULATIONS IN IRISH LAKES

M. O'Grady, Central Fisheries Board.

QUANTIFICATION OF TROUT STOCKS IN AN ALKALINE RIVER FISHERY

W. S. T. Champ, Central Fisheries Board.

ADVANCES IN THE STUDY OF PELAGIC FISH STOCKS IN IRELAND

J. Molloy, Department of Fisheries and Forestry.

GENETIC VARIATION IN IRISH BROWN TROUT POPULATIONS: IDENTIFICATION AND CONSERVATION OF STOCKS

C. Fleming and A. Ferguson, The Queen's University of Belfast.

THE USE OF BIOCHEMICAL GENETICS TO DISTINGUISH POPULATIONS OF ATLANTIC SALMON *SALMO SALAR*

T. F. Cross and J. A. Healy, Salmon Research Trust.

24 April, 1981.

SESSION 3. *AQUACULTURE AND HEALTH*

Chairman : Dr. W. R. Kelly,
Professor of Veterinary Medicine,
University College, Dublin.

THE DEVELOPMENT OF RAINBOW TROUT FARMING IN IRELAND

Jacqueline Doyle, Department of Fisheries and Forestry.

STUDIES IN LATENT FURUNCULOSIS IN HATCHERY-REARED ATLANTIC SALMON

Anita Scallan and Peter R. Smith, University College, Galway.

NEPHROCALCINOSIS IN FRESHWATER AND SALTWATER-FARMED RAINBOW TROUT IN IRELAND

Maire F. Mulcahy, Noeleen Collins and Thérese McAuliffe, University College, Cork.

THE PARASITES OF SALMON *SALMO SALAR* L. AND TROUT *SALMO TRUTTA* L. IN THE RIVER SHOURNAGH

R. D. Fitzgerald and Maire F. Mulcahy, University College, Cork.

LYMPHOMA IN THE PIKE *ESOX LUCIUS* L. IN IRELAND: A REVIEW

Maire F. Mulcahy, University College, Cork.

HAEMOGLOBIN AND THE SALMON-GRILSE PROBLEM

N. P. Wilkins, University College, Galway. (Read in title only).

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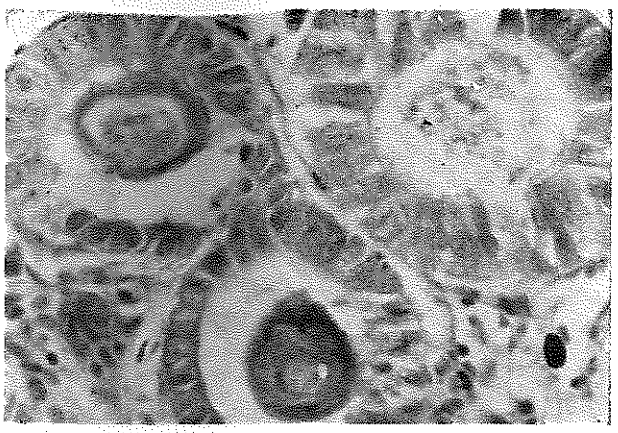

Figure 1. Section of kidney from saltwater reared rainbow trout showing basophilic laminated calcium-containing casts within degenerate kidney tubules (H & E).

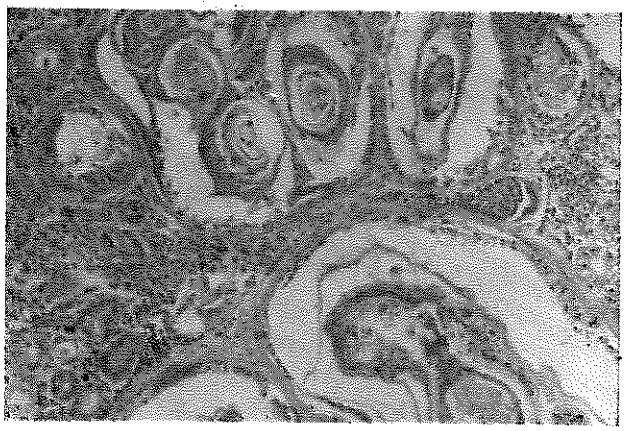

Figure 2. Section of kidney from saltwater-reared rainbow trout showing extreme dilatation and distortion of tubules and ducts associated with high level of calcium deposition (H & E).

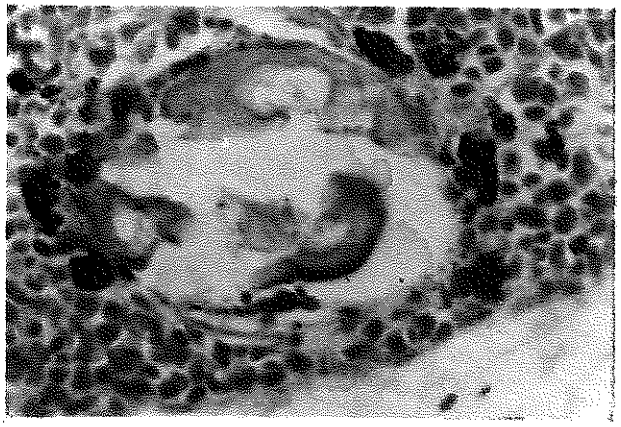

Figure 3. Section of kidney from freshwater reared rainbow trout showing large laminated calcium deposit within a melanomacrophage centre (H & E).

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